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FINAL REPORT

for the

PLASMA PHYSICS AND ENVIRONMENTAL PERTURBATION LABORATORY

Volume II - TECHNICAL REPORT

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PART 1

DEVELOPMENT OF BASIC CONCEPTS

of

PPEPL EXPERIMENTS

1.1 INTRODUCTION

The major emphasis of the present study was to develop a PPEPL concept with the widespread and continuous participation of the scientific community. Table 1 summarizes the methods of interaction that formed the foundation of the the laboratory development throughout the study:

Table 1.1

- METHODS OF INTERACTION.
  - Mailing of initial letter and questionnaire (Nov. 30, 1971).
  - Extensive Follow-up and iterations with potential investigators. Direct contacts to solicit experiment concepts.
  - Four science advisory board performance reviews, plus correspondence with SAB members.
  - Liaison with three working groups led by science advisory board members.
  - Formal talks on PPEPL at scientific meetings and at university seminars.

As indicated above, the present concept of the Plasma Physics and Environmental Perturbation Laboratory was developed with the widespread participation of the scientific community, and this extensive scientific input reflects the growing awareness of the need to carry out controlled experiments in the space plasma. In November of 1971 a questionnaire, together with a brief description of possible shuttle sortie mission capabilities (see Table 1.2), was circulated to 280 scientists in the United States and fifteen foreign countries. This solicitation yielded a large number of valuable responses, and to date letters describing more than a hundred and eighty experiment concepts in the PPEPL area have been received from scientists in the U S. and elsewhere (see Table 1.3).

Table 1.2

Contents of November 30, 1971 Letter
(280 Copies Sent Out)

1. Cover letter from F. L. Scarf explaining.

    (a) The purpose of the solicitation

    - To inform the community
    - To broaden interest in PPEPL/Shuttle
    - To learn if a strong case could be made for PPEPL
    - To obtain potential user information on experiments, and PPEPL requirements.

    (b) The type of new active science investigations desired.

    (c) The concept of the laboratory as a national facility

    (d) Typical orbits, weight capabilities, booms, etc.

    (e) Obvious problem areas (EMI, outgassing, high spacecraft speed).

2. Science advisory board membership list.

3. Summary of the Blue Book Plasma Physics Areas.

4. A preliminary instrument list and preliminary design concepts.

5. Questionnaire.

Table 1.3

Breakdown of 206 Individual Experiment Concepts

(Including Miscellaneous Comments)

TOTAL:	United States: 156		
	Foreign 50		
U.S.:	Universities. 98 (from 29 institutions)		
	Industry or Non-Profit. 29 (from 13 institutions or companies)		
	Government: 29 (from 7 agencies)		
FOREIGN.	Australia	Germany	Japan
	Canada	India	Netherlands
	England	Israel	New Zealand
	France	Italy	Sweden

This information obtained from the initial questionnaire clearly indicated that a large number of experienced scientists are now seriously considering ways to carry out controlled experiments in the space plasma environment of the earth. The ideas for these studies first arose naturally when some early active experiments provided unplanned but invaluable information on cause and effect relations in the magnetosphere and ionosphere. For instance, the high altitude nuclear explosions of the early 60's gave new information on particle injection, wave generation, wave-particle pitch-angle scattering, and large-β effects, including turbulent diffusion. The Alouette and ISIS RF sounding experiments opened new fields involving wave resonances, wave-particle heating, wave-wave interactions, and parametric instabilities. Similarly, the triggering of magnetospheric emissions by ground-based VLF transmitters suggests an obvious generalization to a controlled satellite-borne, wave-particle interaction study. In recent years, there has also been an increasing emphasis on the implementation of carefully-designed active experiment programs using ground -based transmitters, sounding rockets, and unmanned spacecraft. For example, electron accelerators were flown to produce artificial auroras, to study beam-plasma instabilities, and to analyze trapped particle orbits. In addition, radio waves were used to modify the ionospheric characteristics and artificial tracers were used to study field line topology and particle drifts

Because of this extensive background (summarized in Table 1.4), most of the elements of a Plasma Physics and Environmental Perturbation Laboratory are in an advanced state of development, and it is suitable to conceive of PPEPL as a laboratory facility in which standardized diagnostic instruments and data processing modules are furnished as core equipment. It is intended that the prospective investigators will be able to carry out many experiments using only core equipment, but provision will be made for the integration of certain experiment-unique equipment as well.

Table 1.4

Previous Studies in the Magnetospheric Physics Area

- PASSIVE OBSERVATIONS, 1958 TO PRESENT

  Explorer, OGO, Injun Series (59 spacecraft)
  Ground based networks (whistlers, micropulsations, hiss, chorus, auroral displays, and storms)
  Passive rocket payloads

- SOME UNPLANNED "EXPERIMENTS"

  Johnson Island blasts
  Alouette-ISIS resonances and particle heating
  Stimulation of emissions by ground-based transmitters

- RECENT OR PLANNED ACTIVE EXPERIMENTS

  Wave-injection (ground-based, rockets, Mother-Daughter
  Accelerators and particle guns (rockets, Mother)
  Releases (rockets)

1.2 SOLICITATION OF EXPERIMENT CONCEPTS FOR PPEPL

The responses to the November 1971 circular letter were first organized into eight general areas of scientific interest. A description of these areas is contained in Table 1 5. For each general experiment area, specific subtopics were designated. These are described in Table 1.6, and Appendix 1 contains a list of names and affiliations for the individuals or groups whose responses to the November 1971 letter are described in the table. Each subtopic has a roman code letter listed in the table, and these code letters are repeated in the appendix, so that names can be associated with proposed experiment concepts in a general way.

The initial responses from the scientific community outlined in Table 1.6 and in Appendix 1 provided a very important technical baseline for development of preliminary PPEPL configuration concepts, instrumentation specifications,

Table 1.5

DESCRIPTION OF PPEPL AREAS OF INTEREST

EP	(Energetic Particles and Tracer Experiments): Experiments designed to increase knowledge of the configuration of the geomagnetic field and the processes that provide stable or quasi-stable trapping of energetic particles.
BP	(Beam-Plasma Interactions) Experiments emphasizing interactions of beams (generated by electron or ion guns on the PPEPL) with the ambient plasma This category includes artifical auroras.
WP	(Wave-Particle Interactions) Experiments emphasizing the interactions of certain plasma particles with locally generated waves. These experiments utilize wave modes extending over a large frequency range (fractions of Hz to many MH_z) and the interactions of interest generally take place near the PPEPL or on field lines passing through the spacecraft.
WC	(Wave-Characteristics). Experiments emphasizing the study of wave propagation and damping characteristics, plasma instabilities, and wave-wave interactions.
WS	(Wake and Sheath) Experiments designed to study the wake or sheath around orbital bodies
MM	(Magnetospheric Modification) Experiments designed to produce large scale perturbations in the magnetosphere or ionosphere and to identify the underlying mechanisms
PP	(Plasam Physics in Space) Experiments in this category are essentially those laboratory-type experiments that can be performed better in space to take advantage of large volumes, high vacuum conditions and/or weightlessness Also experiments which use the ambient plasma present in the upper ionosphere.
PD	(Propulsion and Devices) These experiments ultimately have applied goals The propulsion studies utilize ion thrusters or (v x B) electric fields The other general area here involves development of new diagnostics and resolution of outstanding problems connected with use of standard diagnostic techniques on unmanned rockets and satellites

Table 1.6

PPEPL EXPERIMENT SUB-AREAS

WAVE CHARACTERISTICS   35 EXPERIMENT CONCEPTS, INCLUDING STUDY OF

- Linear and non-linear dispersion relations, damping, growth, $\underset{\sim}{k}\ \underset{\sim}{B}$, $\underset{\sim}{k}\ \underset{\sim}{U}$ dependence,
- Generalized Bernstein modes (ion and electron branches) using resonance techniques,
- Parametric instabilities,
- Long-delay echoes,
- Non-linear effects and 3-wave interactions,
- Generation of low frequency electromagnetic waves from within the plasma at ULF ($f < f_c^+$) ELF ($f < f_p^+$) and VLF ($f < f_c^-$),
- Wave packets in a dispersive medium

WAVE-PARTICLE INTERACTIONS   18 EXPERIMENT CONCEPTS, INCLUDING STUDY OF

- Cyclotron resonance instabilities, pitch angle diffusion, acceleration,
- Turbulent resistivity,
- Generation of electromagnetic waves by phased electron or proton gun arrays

PROPULSION AND DEVICES   22 EXPERIMENT CONCEPTS, INCLUDING STUDY OF

- Problems of Langmuir probes, Faraday cups, dc electric-field probes in space,
- New techniques for measuring small plasma drifts (Doppler effects), dc electric fields, other devices,
- MPD arcs in large volumes,
- Plasma beam-ambient plasma interactions, for ultimate propulsion applications

MAGNETOSPHERIC MODIFICATION   21 EXPERIMENT CONCEPTS, INCLUDING

- Radiation belt precipitation by changing wave growth rates,
- Generation of high-power VLF waves to trigger precipitation events,
- Ionospheric heating and spread F studies (parametric instabilities, RF heating),

PLASMA PHYSICS IN SPACE   15 EXPERIMENT CONCEPTS, INCLUDING SEVERAL OF THE ABOVE, PLUS STUDIES OF

- Neutral gas-plasma beam interactions,
- The generalized Ohm's law,
- Levitron-type confinement devices (deployed magnet),
- Motion and configuration of a spinning conducting fluid

BEAM-PLASMA INTERACTIONS   23 EXPERIMENT CONCEPTS, INCLUDING STUDY OF

- Beam instability and turbulence, return currents, neutralization, collisionless dissipation and acceleration mechanisms,
- Artificial auroras,
- Response of the ionosphere to controlled fluxes of suprathermal particles, modification of ionospheric conductivity,
- Artificial mid-latitude SAR red arcs,
- Models of solar flare radiation mechanisms, and mode-mode coupling

ENERGETIC PARTICLES AND TRACERS   20 EXPERIMENT CONCEPTS, INCLUDING STUDIES OF

- Field line topology,
- Parallel and perpendicular electric field,
- Charged particle orbits and life histories

WAKE AND SHEATH   29 EXPERIMENT CONCEPTS, INCLUDING STUDY OF

- Wake and sheath regions around known targets,
- Validity of current theories (size, shape of perturbed region, potential distribution, Cerenkov cones in wakes),
- Stability of W-S regions   variation when body is biased   Effects of different surface materials, body shapes,
- Effects of W-S on antenna impedance, particle probes,
- Generalized Terrella experiments with large magnets

and other significant mission requirements. On May 8, 1972 a second circular letter was sent to all scientists listed in Appendix 1, and in many cases there were additional direct contacts to clarify technical points

During the course of this study we also had continuous interactions with several NASA-formed advisory panels (see Table 1.1) concerned with PPEPL and the sortie missions. Marshall Space Flight Center established a PPEPL Science Advisory Board (SAB), and three discipline-oriented working groups were formed by members of the SAB to examine certain problems in greater depth. Appendix 2 lists the membership of the panels and working groups. The PPEPL concept was also discussed at meetings of the Atmospheric and Space Physics Working Group, a NASA Headquarters advisory body concerned with several possible future missions (see Appendix 2). Finally, the PPEPL concept was widely discussed at open scientific meetings. Invited talks on this topic were presented at the American Physical Society Meeting of the Plasma Physics Division (Monterey, California, November 1972), the AAAS Symposium on Space Shuttle Payloads (Washington, D C., December 1972), the Spring Meeting of the American Geophysical Union (Washington, D.C., April 1973), the Seventh ESLAB Symposium (Saulgau, W. Germany, May 1973), the Workshop on Controlled Magnetospheric Experiments, (IAGA, Kyoto, Japan, September 1973), and at the Second Conference on Payload Interfaces with Shuttle or Tug (Huntington Beach, Calif , September 1973).

These discussions of the PPEPL program at the advisory panel meetings and at scientific symposia provided many additional informal suggestions for experiment concepts, and in several areas the material in Table 1.6 (taken from the original questionnaire) does not adequately document the depth or variety of science likely to be proposed for a flight program. For instance, in the

Energetic Particle and Tracer area, the initial suggestions for release experiments involved release of Barium or Lithium to measure dc electric field distributions and to study particle entry into the magnetosphere More recent suggestions, not listed in Table 1.6, include use of Helium releases to trace the Polar Wind, and release of electron acceptors (such as sulfur hexafluoride) to disrupt ionospheric currents so that magnetosphere-ionosphere coupling can be studied in a controlled way. Another example involves alternate uses for the magnetoplasma dynamic (MPD) arc proposed by the Princeton Group (experiment PD-16) for flight on PPEPL The original experiment concept, in the Propulsion and Device area, was proposed so that a convection-free arc source could be tested in the unbounded space plasma, the propulsion capabilities could then be evaluated without concern about wall effects that always enter in ground-based laboratories However it has been noted that this very high power device provides a unique capability as a plasma source for many other kinds of experiments, and we include the MPD arc as a baseline plasma accelerator for PPEPL. In general, we have tried to generalize the PPEPL concept to provide a facility capable of conducting many more experiments than the ones listed in Table 1.6.

1.3 SUMMARY OF SCIENCE CONCEPTS AND REQUIREMENTS

The original grouping of experiment concepts into the eight areas of Table 1.5 was motivated by the need to define instrumentation requirements so that commonality studies could be conducted. However, from a broader point of view, a more suitable grouping involves the science objective, rather than the experimental technique. From this viewpoint, we would classify the suggested science into the two broad but overlapping disciplines of space physics and plasma physics

The most significant space physics experiment concepts involve natural follow-ons to the present phase of magnetospheric-ionospheric exploration based on use of unmanned spacecraft. It seems to be widely recognized that after the completion of the International Magnetosphere Study (1976-1978), the major dynamical phenomena that occur in nature will have been classified, and there will be general knowledge of where and when important events take place. For the decade of the eighties, many scientists now appear to feel that the field will be ripe for a new stage of research, in which the primary objective will be to understand the detailed mechanisms and the physical interactions which bring about the observed dynamical phenomena. Many controlled experiments in the Energetic Particles and Tracers area are designed to provide unambiguous answers about magnetospheric configuration, particle entry, energization and loss processes, distributions of electric field, and magnetospheric convection. A number of experiments in the Beam-Plasma and Wave-Particle Interaction areas are designed to study basic magnetospheric plasma instabilities that can limit the stably-trapped flux, provide the wave-particle scattering that leads to anomalous resistance (and hence parallel electric fields), modulated auroral phenomena, and introduce coherence effects into magnetospheric radiation processes Other experiments in these areas, and in the Magnetospheric Modification area, are aimed at studying the mechanisms that drive large scale dynamical processes (coherence effects in auroras, triggering of substorms, energy transfer in red arcs, magnetosphere-ionosphere coupling) by introducing major controlled perturbations that can generate the phenomena in a known way (e.g , the artificial aurora), or can vary the natural process (e.g., by modifying ionospheric conductivity, injecting waves to scatter particles, injecting cold plasma to modify instability growth rates).

The Shuttle sortie missions also provide a unique opportunity to investigate fundamental and applied plasma physics phenomena that are not necessarily or specifically related to geophysical problems. All the Shuttle orbits are immersed within a natural, magnetically-confined plasma in a high vacuum, with scale lengths that can be enormous in comparison with those available in ground-based plasma laboratories. It is possible to investigate important phenomena free of the sometimes dominant influence of walls. The weightless orbital conditions can be extremely important to the potential experimenter who may wish to study such diverse phenomena as long-term plasma confinement in a field produced by a levitated magnet, the interaction of a spinning conducting fluid with the ambient geomagnetic field and plasma, or the behavior of convection-free plasma arcs; in the ground-based laboratory all of these studies would be strongly affected by gravity.

In some general areas it appears that the availability of one or more of these unique space laboratory conditions is of vital importance. For instance, some information on low frequency electromagnetic wave modes in a magnetized plasma (whistlers) can be obtained in a ground-based laboratory, but the conventional experiment is generally restricted to near-field analysis for the specific wave modes allowed in the fixed and finite plasma chamber Because of this, it is not possible to study the complete warm plasma dispersion relations or generalized radiation processes and wave-wave coupling effects in the ground-based laboratory. In some cases the finite chamber size restrictions limit the accessible interactions and preclude study of basic plasma phenomena that are known to occur in nature. For instance, while it may be stated that non-linear beam-plasma interactions have frequently been studies in ground-based laboratories, the finite scale size dictated by laboratory chambers means that the short wavelength electrostatic waves play a predominant role in these experiments. However, the various beam-plasma dissipation processes that occur in nature appear to give rise to intense electromagnetic radiation fields (auroral hiss, solar radio bursts, Jovian decametric radiation, pulsars, etc.), and these mechanisms cannot be studied adequately in small plasma chambers.

In the plasma physics area, the sortie laboratory missions can also provide the scientific community with significant opportunities to carry out short-term experiments involving development and test of new diagnostic devices and investigation of new techniques for plasma propulsion. Long-standing questions involving the plasma physics of the wake and sheath and the behavior of various probes in earth orbit can be studied.

Our analysis of the response from the scientific community suggests that the Shuttle sortie mission capabilities are very well matched to the needs in the space physics and plasma physics area for a meaningful experimental program to be conducted in the eighties. The region outside of the shuttle is a natural plasma laboratory (collisionless at the higher shuttle altitudes over the poles, and collision-dominated at lower shuttle altitudes nearer to the equator). The scientists on-board can conduct true, controlled experiments from within the pressurized sortie lab chamber, because the Shuttle weight and power capabilities will allow massive and high power perturbation sources to be carried. The polar shuttle orbits also traverse directly the important auroral and ionosphere-magnetosphere coupling regions of prime interest to space scientists.

Part 2

IDENTIFICATION OF INSTRUMENTATION

2.1 INTRODUCTION

We have described in Part 1 how the responses to the questionnaire were used to define subareas of closely related experiments within each of the main eight areas (see Table 1.6). Each subarea was then analyzed for instrumentation and mission requirements. The requirements were then subjected to a commonality analysis for overall laboratory definition Figure 2.1 shows a flow plan of how this analysis and experimenter suggestions were used to define the instrumentation for the PPEPL. One of the points in the laboratory definition was the question of desired vs required instrumentation. Many candidate experimenters had an instrumentation list which was larger than required by the experiment, but which could prove useful should peripheral data later be desired. (Table 2.1 gives a listing of the instrumentation categories that were suggested by the experimenters' requests.) The commonality analysis differentiated between these two types of instrumentation in the laboratory design

Table 2.1

Instrument Categories Identified

A.	Plasma Probes	J.	Particle Accelerators
B.	Magnetometers	K.	Shaped Charges
C.	Electric Field Meters	L	Cannisters
D.	Energetic Particle Detectors	M.	Radioactive Sources
E.	Gamma-Ray Detector	N.	Gas Releases
F	Optical Equipment	O.	Targets
G.	Transmitters	P.	Balloons
H.	Receivers	Q.	Magnetic Fields
I.	Antennas	R	Ancillary Equipment

Thus three different labs were developed a basic laboratory, an austere version of this, and a growth laboratory The primary difference between the basic and austere laboratories is in the inclusion in the basic lab of a subsatellite launched and controlled from the Shuttle. We discuss these three

INSTRUMENTATION REQUIREMENTS FLOW

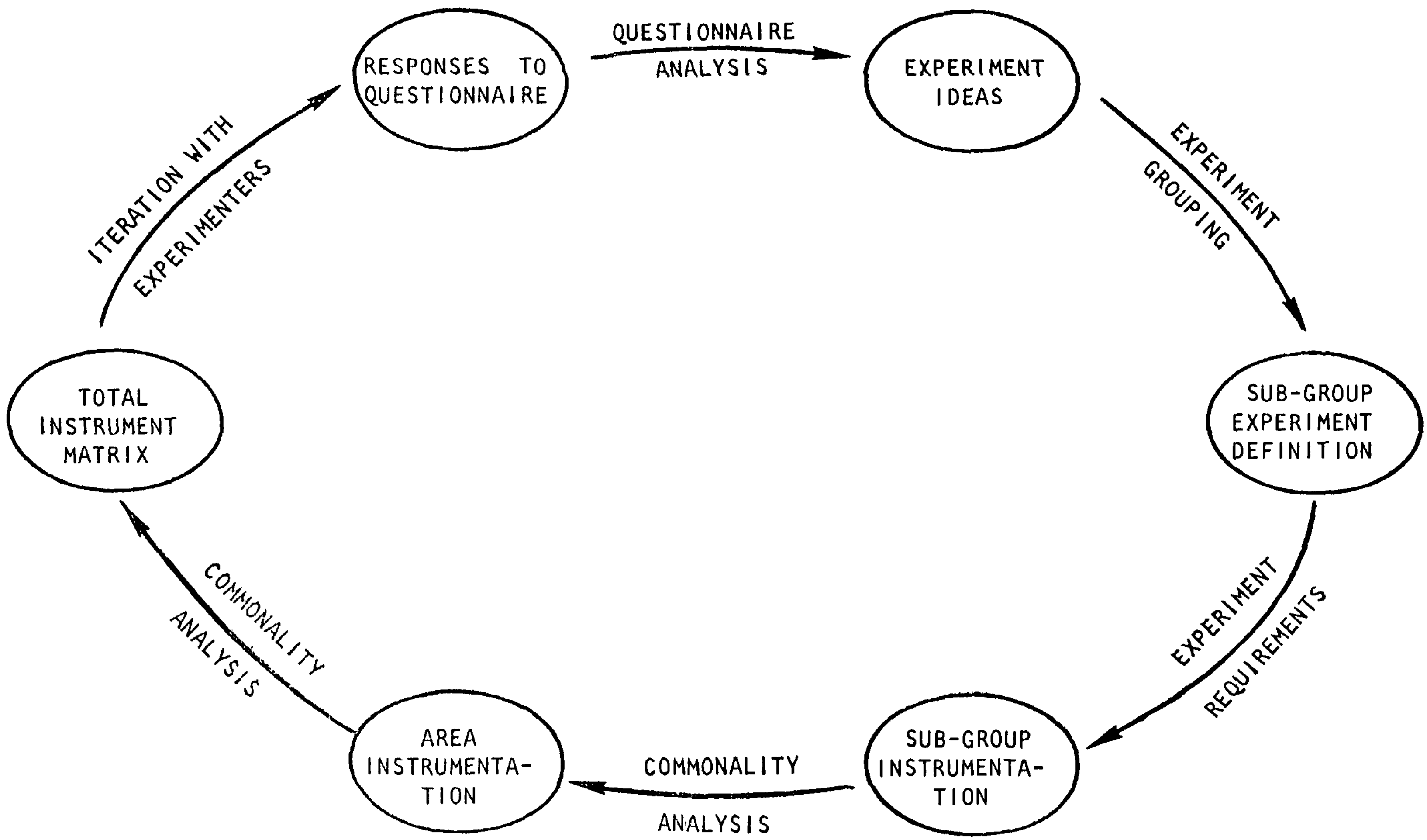


Figure 2.1

labs in more detail in Section 2.2. From this total list of instrumentation requirements we identified five major subsystems as requiring special emphasis in the study. These five are:

- Accelerators
- Transmitters
- Booms
- Gimbaled Platform (incl. optics)
- Subsatellite(s)

In Table 2.2 we show how four of these major subsystems are required by experiments in each of the eight main experiment groupings. The second column, labeled PPEPL Only, refers to the absence of booms and subsatellites on the laboratory, but does not include any consideration of the presence of accelerators or transmitters. The gimbaled platform was not included in Table 2.2 because it is expected to be a basic part of the laboratory and does not represent a major resource requirement impact on the shuttle system.

In Table 2.3 we summarize the requirements of each of the major subsystems. Here the deployable units have been broken out separately. These include barium cannisters, shaped charges, chemical releases, and deployable balloons

Each of the five major subsystems will now be discussed independently.

2.2 ACCELERATOR REQUIREMENTS

A tentative accelerator group configuration under study for initial PPEPL flights consists of an electron gun, an ion gun, and a very high power plasma accelerator.

The electron gun design goal is 1 ampere of electron flow at a minimum acceleration energy of 10 keV, and a full width of 5 degrees in electron angular divergence. A high current, high power electron beam with these general

Table 2.2

R E Q U I R E M E N T S

Area	No. of Experiments	PPEPL Only	PPEPL & Booms	Sub-satellites	Electron/ Ion Beams	Antennas/ Transmitters
Energetic Particles and Tracer Experiments	9	3	1	3	1	0
Beam-Plasma Interactions	15	0	6	8	10	2
Wave-Particle Interactions	14	5	9	9	2	14
Wave-Characteristics	23	5	20	16	3	18
Wake and Sheath	15	3	12	12	2	6
Magnetospheric Modification	6	1	4	2	4	4
Plasma Physics in Space	5	3	2	1	1	1
Propulsion and Devices	13	2	6	7	1	2
TOTALS	100	22	60	58	24	47

Table 2.3

INSTRUMENTATION REQUIREMENTS

	WEIGHT	VOLUME	PEAK POWER	DATA
A-ACCELERATORS	1215 kg	$4\ M^3$	to 10 kW	2×10^3 bps
T-TRANSMITTERS	210	0.5	to 10 kW	3×10^2
B-BOOMS	525	1.6	280 W	10^6
G-GIMBALED PLATFORM	126	6 3	210 W	10^6
D-DEPLOYABLE UNITS	820	0 6	--	--
DS-DEPLOYABLE SUBSATELLITE	270	1 6	234 W	2 Mhz, 3×10^5 bps

POINTING. $\pm 0.5°$ to $\pm 1.0°$

specifications has been configured so that the exit beam density is small compared to space plasma electron density. The principal mechanism for continued propagation (away from PPEPL) of these high current beams without disruption would be a neutralizing action by the space plasma sufficient to prevent space charge blow-up of the ejected beam. In this regard, the presence of the space plasma ion provides space charge neutralization for the beam electron, and the mobility of space plasma electrons is, hopefully, sufficiently fast to prevent unstable space charge wave growth in the accelerated beam (the hope here is to <u>limit</u> the growth rates for instabilities in the beam). The beam-in-plasma instabilities and appropriate wave-particle interactions are currently under study.

The configuration of the electron beam calls for a single gun followed by an expansion stage and a refocusing stage. If lens action in the refocusing stage may be made to be sufficiently invariant over the total flow, the phase space density for the ejected electrons may reach some two orders of magnitude in excess of previously realized electron beams for space experimentation. A block diagram of the elements in the electron beam system is shown in Figure 2.2.

The original proton gun design goal of 1 ampere at 50 kilovolts was modified because of recent developments in high current ion beam production. The characteristics of high current, high power, multi-aperture ion sources capable of providing beam currents of protons in excess of 10 amperes at 20 kilovolts were studied analytically. Total energy expenditures over 20 kilo-Joules per burst appear possible for pulsed operation. Charge exchange problems and possibilities were also assessed (intense beams of neutral hydrogen may be released), and beam divergence data were analyzed. It appears that currents of

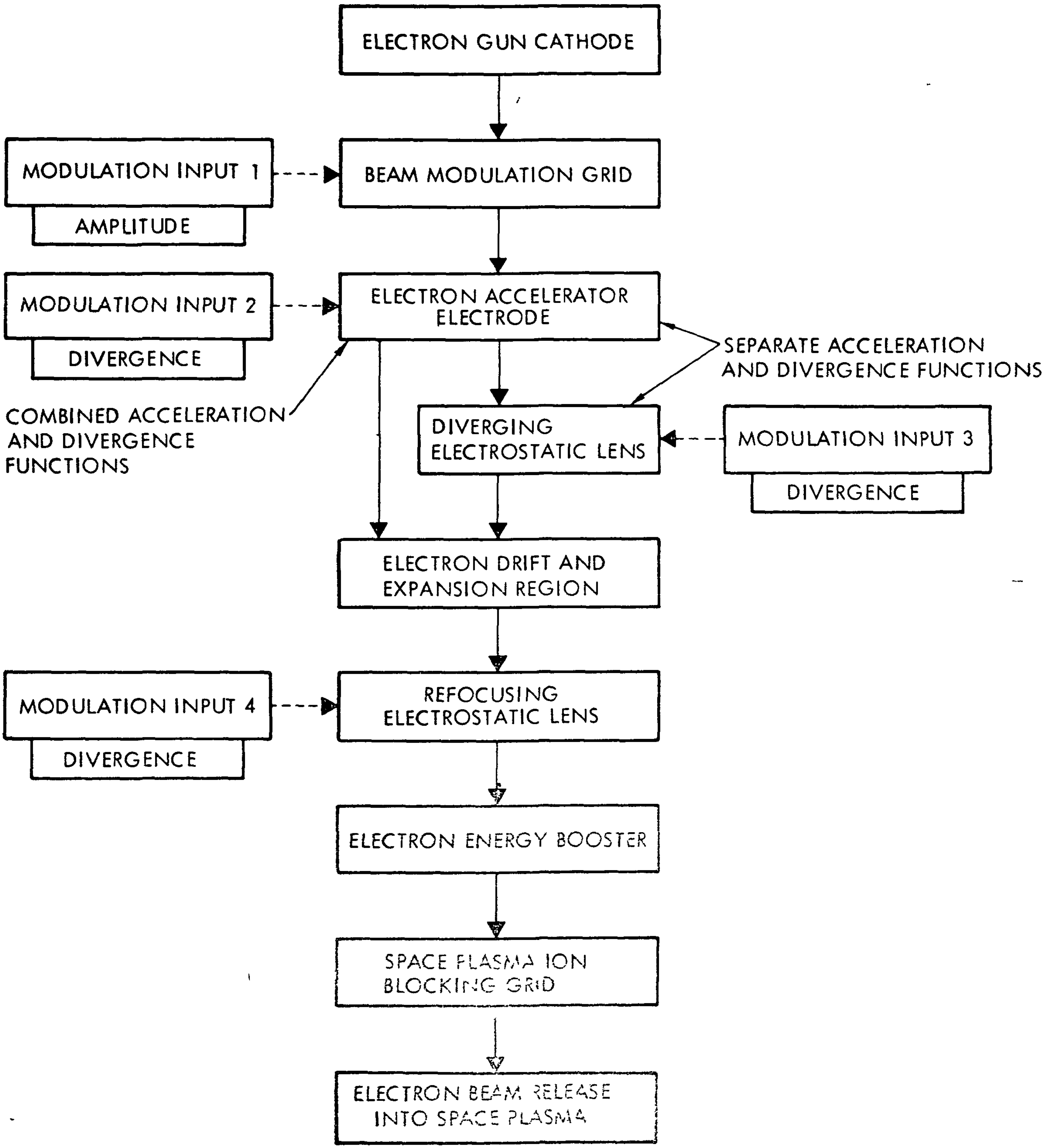


Figure 2.2. Block Diagram of Elements of Overall Electron Beam System

protons an order of magnitude larger than the original design goal of the PPEPL proton accelerator may be released from the spacecraft in a highly collimated flow. If it is desired, the accelerated proton current may be held fixed, while the release energy is lowered. A practical limit to the use of this accel-decel technique would appear to be approximately 4000 volts for the final release energy. At this point, the total cone of velocity directions would be approximately 6-10°. A drawing of the main features of the basic proton accelerator is shown in Figure 2.3.

The likely element as a very high power plasma accelerator is a magneto-plasma-dynamic (MPD) arc. In laboratory tests, these devices have been operated with power levels up to 2×10^8 watts (on Argon) The MPD arc is inherently adaptable to pulsed operation, and it possesses a wide range of possible output power levels. In the range up to 25 megawatts, the energy storage bank can simply consist of electrolytic capacitors. For instance, with 10 millisecond pulses and 25 megawatt power levels, a 500 kilogram capacitor bank (2 cubic meters) would suffice, the remainder of the device would require another 10 kilograms. A typical beam contemplated would have 10,000 amperes of 200 eV argon ions, and such a device would allow high energy plasma deposition onto a field line in milliseconds (see Figure 2 4)

It is also planned that a low energy (5-20 eV) electron gun will be mounted on the end of the boom.

Table 2.4 summarizes the display and control requirements for each of the three accelerators discussed above. We have also included in this table the supporting measurements that will be required to diagnose proper operation of the accelerators.

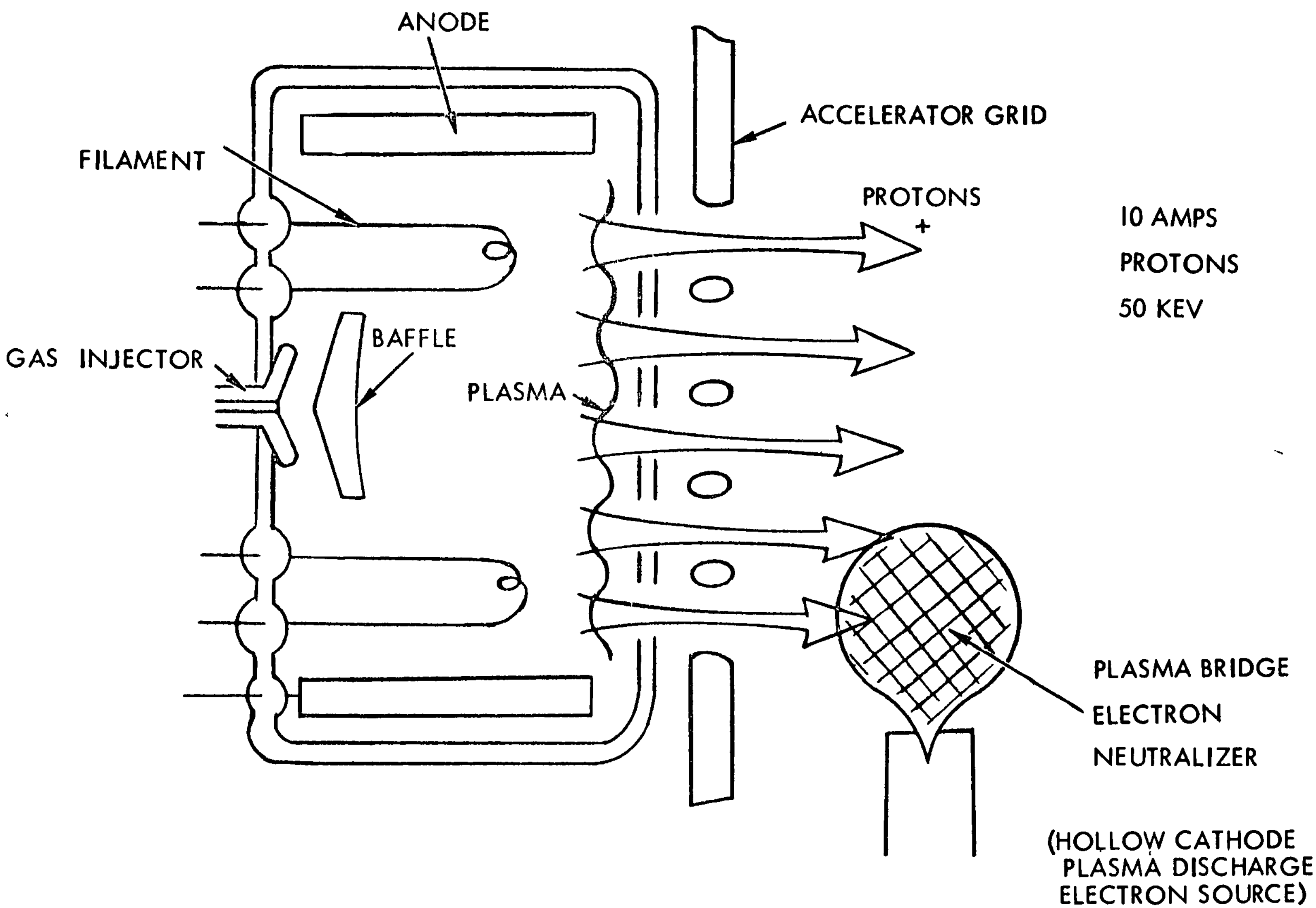


Figure 2.3. Source & Beam Neutralizer for Proton Accelerator

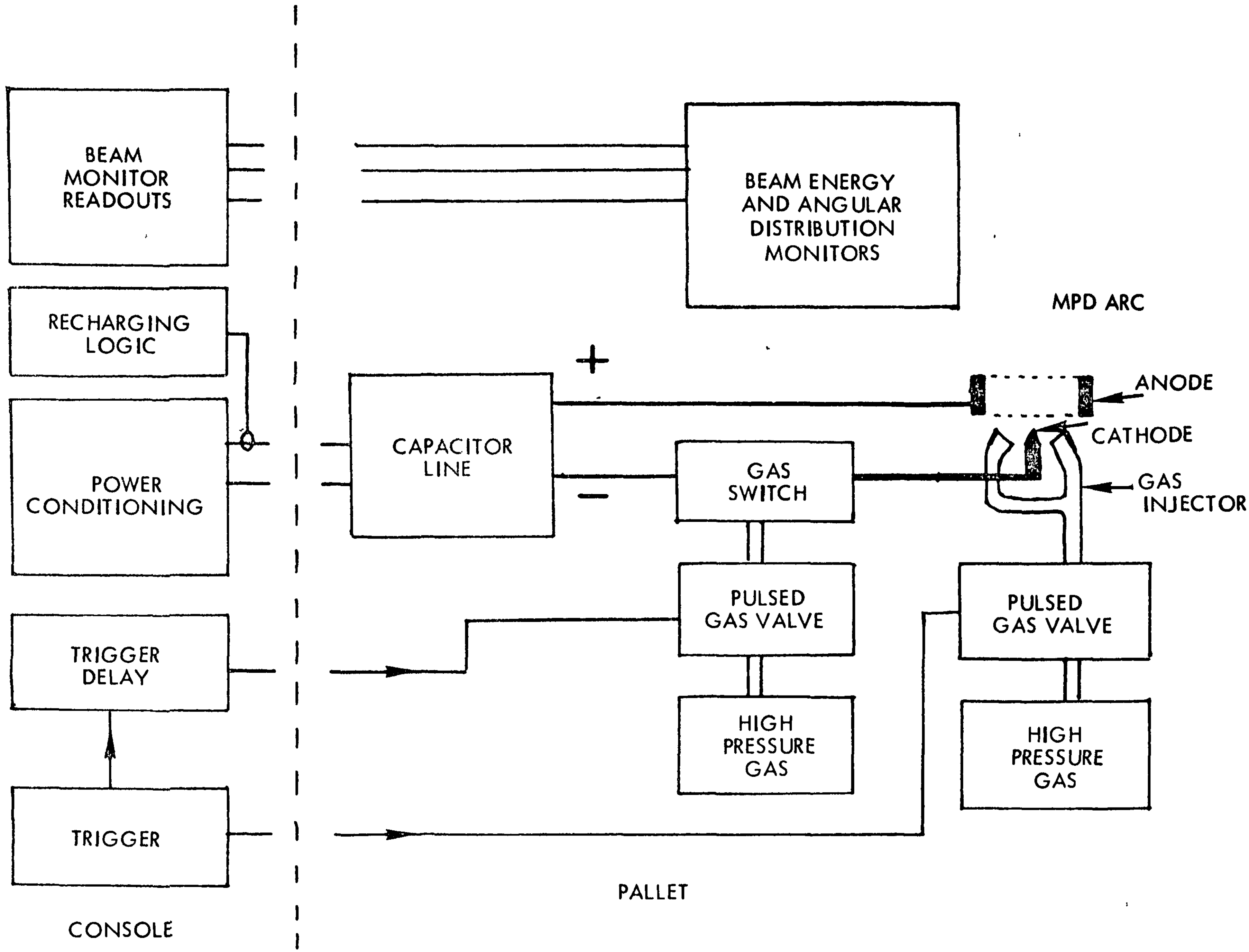


Figure 2.4. Block Diagram of Elements of Very High Powered Plasma Accelerator

Table 2.4

Accelerator Requirements

ION ACCELERATOR	ELECTRON ACCELERATOR
9 Control Units	6 Control Units
11 Display Units	11 Display Units
Diagnostic Instruments	Diagnostic Instruments
Accelerator Gimbaled Platform	Accelerator Gimbaled Platform

MPD ARC
6 Control Units
11 Display Units
Diagnostic Instruments

2.3 TRANSMITTER REQUIREMENT

A high-powered transmitter will be used to modulate long sounding antennas (up to 1000 feet per element, as on Radio Astronomy Explorer). It is possible that HF and RF potential amplitudes up to 20 kilovolts will ultimately be requested to drive the electric dipoles (the Alouette and ISIS transmitters already put out several kilovolts at these frequencies, and the 20 kV requirement is not a significant extension of existing tehcnology) The major present uncertainty in this area concerns the low frequency bound for the high powered transmitter. At frequencies well below the local electron plasma and gyrofrequencies, some ill-defined problems that involve tuning, sheath effects, and dipole unbalance arise. The generation of large amplitude low frequency waves will initially be approached as a PPEPL experiment program, but it would be wise to devote some support to analysis of this important area in the years when specific designs are being formulated.

Table 2.5 summarizes these low frequency transmitting problems along with the type of antennas suggested.

Table 2.5

Low Frequency Transmitting Antennas

TRANSMISSION OF ELECTROMAGNETIC MODES

1. High power levels desired (~500 watts radiated).

ANTENNAS SUGGESTED

1. Magnetic loop radiator.
2. Electric dipole radiator.
3. ac Superconducting loop radiator.

PROBLEMS

1. Coupling to plasma wave mode desired (runaway, sheath problems).
2. Tuning across desired bandwidth (unbalance, high Q)
3. High voltage surge accommodation, or
4. High peak volt-ampere content.
5. Modulation of large superconductive currents.

We show block diagrams in the wave transmission and the wave analysis systems in Figures 2.5 and 2.6. Figure 2.7 is a drawing of a pallet mounted high powered transmitter including the two 330 meter dipole antenna elements mentioned above. The control for this transmitter has been broken down into three frequency ranges with the requirements shown in Table 2.6.

Table 2.6

Transmitter Requirements

2 to 20 MHz 0.2 to 2 MHz 0.3 to 200 kHz	9 Display Units 5 Control Units
330 M Dipole	1 Display, 2 Control Units
Diagnostic Instruments	Varies with Experiment

It has also been proposed that lowest frequency (ELF and ULF) electromagnetic plasma waves can be generated by phased arrays of electron and proton guns, and this investigation should be carried out at an early stage. For the early missions we do not include the possibility of using normal or superconducting loop antennas for wave generation, but this may prove desirable at a later stage. No problems should arise concerning electrostatic wave generation, and simple parallel grid structures mounted on the booms should suffice for many experimenters.

WAVE TRANSMISSION SYSTEM

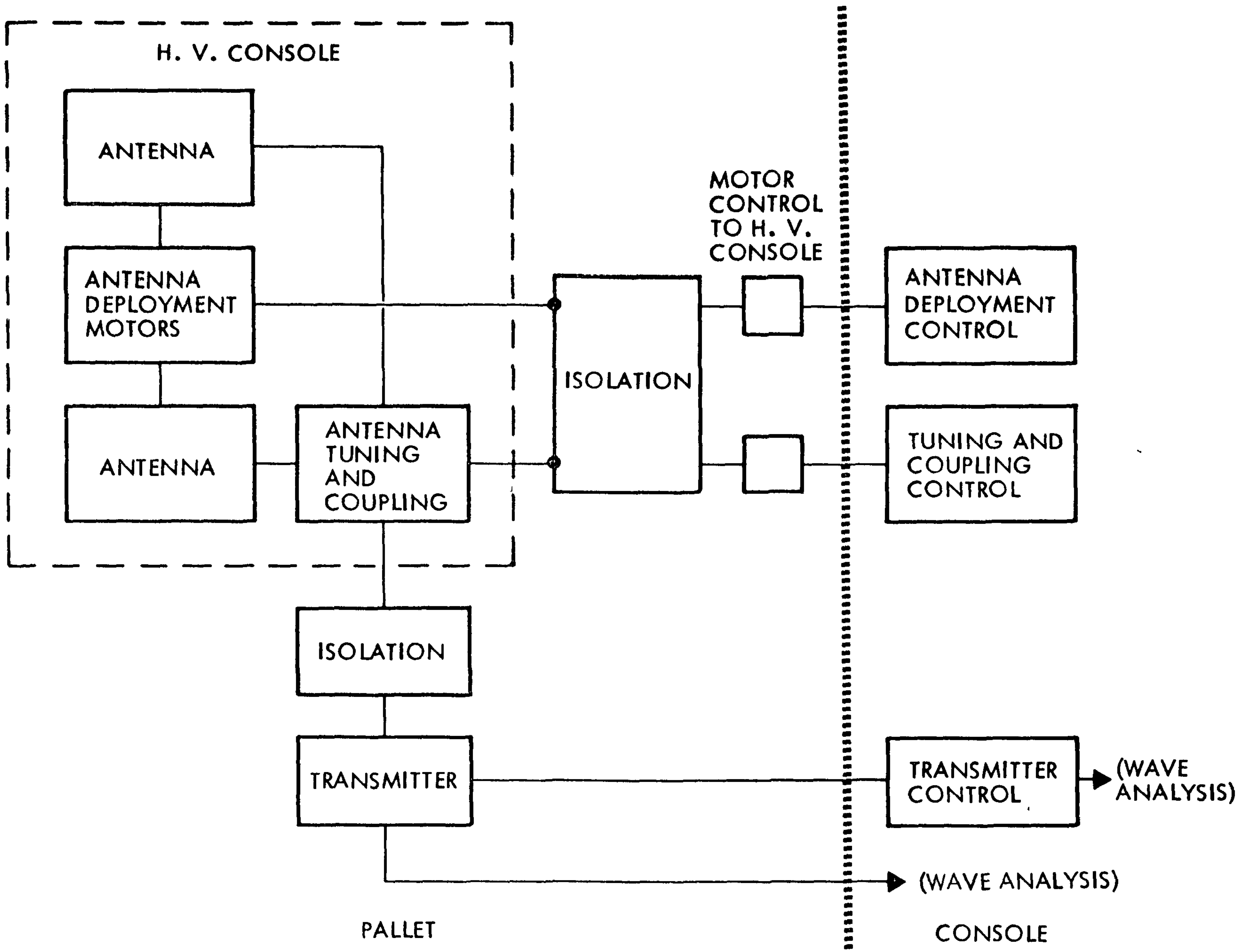


Figure 2.5

WAVE ANALYSIS

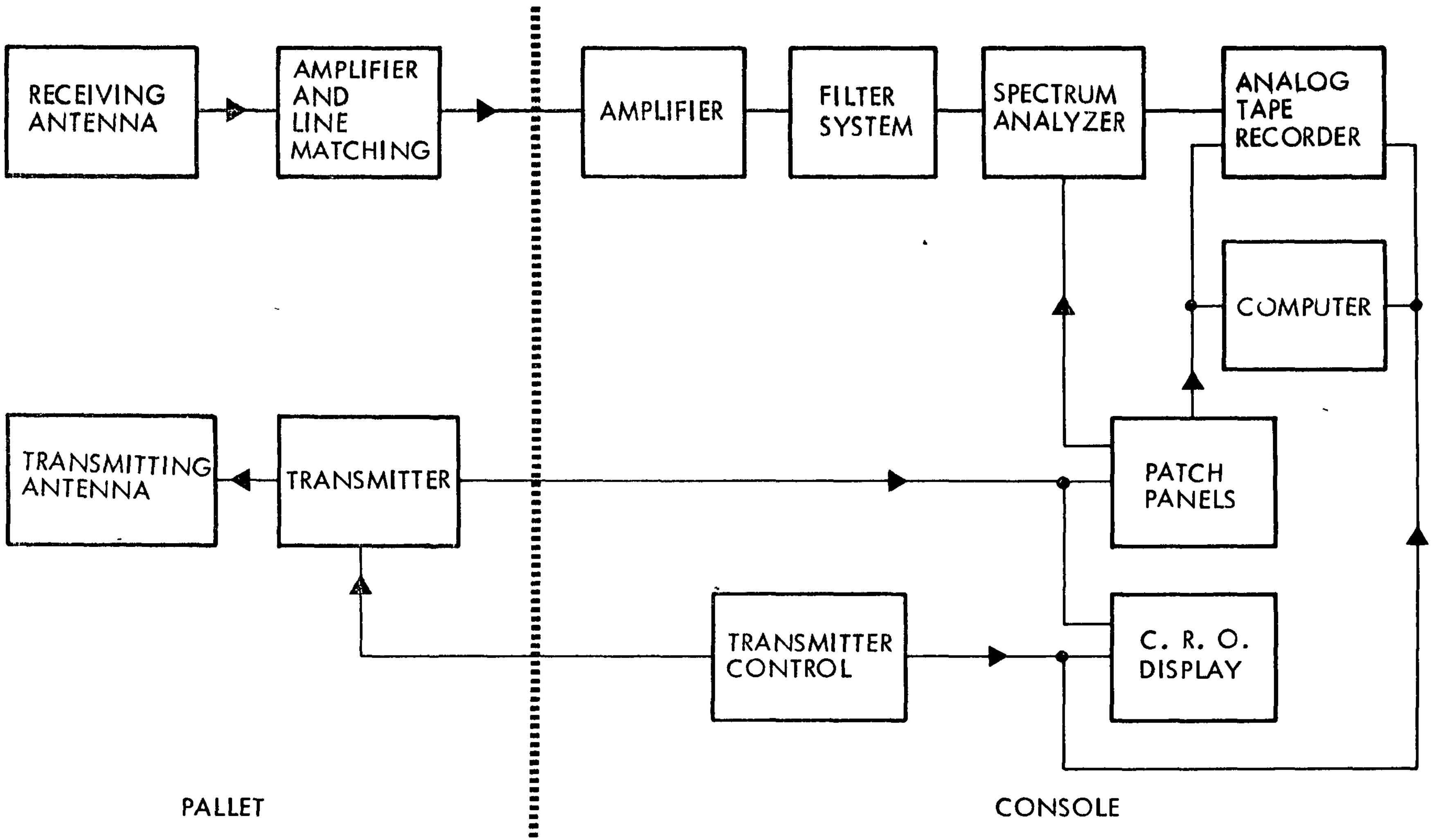


Figure 2 6

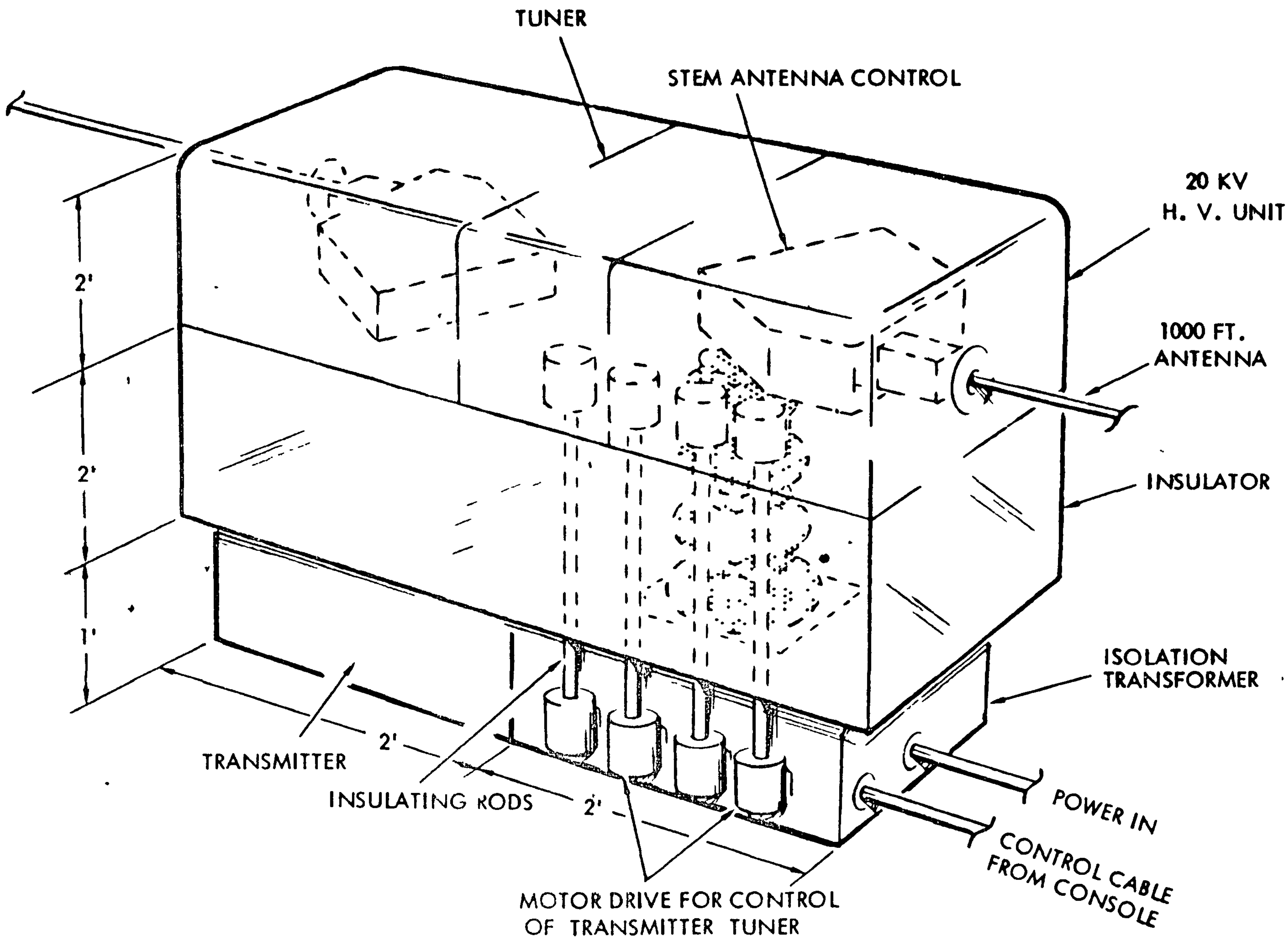

TUNER
STEM ANTENNA CONTROL
20 KV
H. V. UNIT
1000 FT.
ANTENNA
INSULATOR
ISOLATION
TRANSFORMER
2'
2'
1'
2'
2'
TRANSMITTER
INSULATING RODS
MOTOR DRIVE FOR CONTROL
OF TRANSMITTER TUNER
POWER IN
CONTROL CABLE
FROM CONSOLE

Figure 2 7

2.4 BOOM REQUIREMENTS

Most of the candidate experimenters had rather definite or implied requirements for booms as a part of the laboratory. For example, the large EMI and magnetic field levels expected close to the Shuttle make it mandatory that many sensors be remotely deployed.

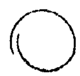
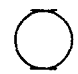
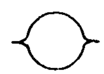
Also, in order to carry out experiments in the plasma physics area, it is very frequently required that active perturbing and sensing equipment be remotely located from the large shuttle-sortie lab system. Requirements varied from relatively short, light weight booms to long (over 100 meters) booms capable of carrying large equipment complements. This wide range of requirements led to the necessity of studying all available boom types as possible candidates for the PPEPL. Figures 2.8 and 2 9 depict the types studied and Table 2.7 summarizes the advantages and disadvantages of each type.

Table 2.7

Boom Types Considered

	Advantages	Disadvantages
Tubular	Extensively tested in space Simple, compact extension mechanism	Solar radiation causes bending and twisting. Least rigidity for a given weight
Continuous Longeron Lattice	Simpler and cheaper than articulated lattice More rigid than tubular boom of same weight. Low thermal distortion	Relatively large stowed diameter, determined by longeron cross-section
Articulated Lattice	Greatest freedom from distortion under solar heating. Best strength to weight and rigidity to weight ratio for large booms	Relatively complicated and expensive.

TYPES OF TUBULAR BOOMS

Tape / Section	Single			Double			Nested		
	Cross section	Name	Ref	Cross section	Name	Ref	Cross section	Name	Ref
Open					BISTEM	34		Nested bistem	34
Overlapped		Stem Tee Moly rod Screen boom	31 22 32 33					Nested stem	31
Interlocked		Tee Trats Moly rod	22 29 32		Interlocked bistem Hinge-lock	34 22			
Welded					Welded seam Mast	35 36			

DETAILS OF INTERLOCKED BISTEM

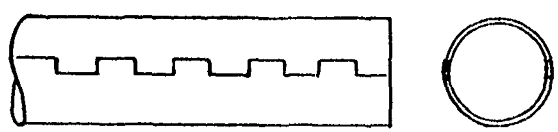
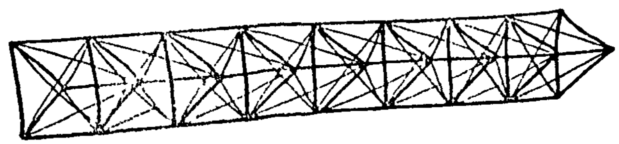
	2 PIECES OF PRE-FORMED SPRING TAPES ARE FLATTENED & ROLLED-UP ON REELS THE EDGES OF THE TAPES INTERLOCK AS THE BEAM EXTENDS. REELS ARE INTERCONNECTED & ROTATED BY AN ELECT. MOTOR & GEAR TRAIN. RETRACTION ACCOMPLISHED BY REVERSING MOTOR.

Figure 18

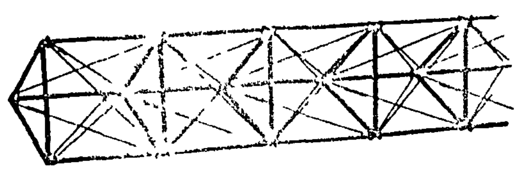
EXTENDIBLE TRUSS STRUCTURES

ASTROMAST COILABLE LATTICE (CONTINUOUS LONGERON)



FIBERGLASS CONSTRUCTION WITH WIRE ROPE TENSION MEMBERS. LONGITUDINAL SECTIONS ARE CONTINUOUS; THE TRIANGULAR BAY SECTIONS ARE RIGID AND PIVOTED ON THE LONGITUDIONAL MEMBERS. RETRACTABLE. FIBERGLASS BATTENS (SIDES OF TRIANGULAR SECTION) ARE BUCKLED TO BEGIN COILING OPERATION.

ASTROMAST ARTICULATED LATTICE



TRIANGULAR SECTIONS ARE RIGID THE LONGITUDINAL LINKS PIVOT AT EACH BAY. FOLDING IS ACHIEVED BY LOOSENING ONE TENSION MEMBER (WIRE ROPE) IN EACH BAY THE TENSION MEMBERS ARE LOCKED AS EACH BAY IS EXTENDED. RETRACTABLE.

Figure 2 9

In our present conceptual design all three types of boom structures have been employed. The tubular type was chosen as most appropriate for antennas; the articulated lattice for main instrument booms and perturbing-source booms that can carry large arrays of instrumentation and sensors; and the continuous longeron lattice as subsidiary booms for deploying individual instruments away from high background areas

The effect on the shuttle of moving a long articulated boom was studied for the example shown in Figure 2 10. The response of the boom tip and of the orbiter to this motion is shown in Figure 2.11. Note that orbiter velocities of ≈0.01°/sec can be expected. (In this model a boom tip mass of ≈25 kg was assumed.) Table 2.8 summarizes the result.

Table 2.8

30 Meter Boom Dynamic Simulation Example

MANEUVER:	Severe 45 degree boom articulation in YZ plane of orbiter axes
TIME DURATION OF MANEUVER	94 sec
MAXIMUM TIP ANGULAR ROTATION	2.5 deg
MAXIMUM INDUCED ANGULAR VELOCITY OF ORBITER	0.01 deg/sec
TOTAL ANGULAR ROTATION OF ORBITER AT TERMINATION OF MANEUVER:	0.5 deg

A similar computer simulation was performed for a 100 meter boom, again with a 25 kg end mass. In this case the effects on the orbiter were unacceptably large. A length of 50 meters was chosen as the best compromise between the scientific requirements and the engineering realities.

2.5 GIMBALED PLATFORM

A large gimbaled platform will be used as a base for a variety of diagnostic instruments requiring pointing. Table 2 9 lists the instruments that will be included on such a platform.

DESCRIPTION OF MODEL FOR DYNAMIC SIMULATION EXAMPLE

[EXISTING SIMULATION PROGRAM CAN READILY HANDLE
ALL ANTICIPATED BOOM CONFIGURATIONS AND MANEUVERS...]

45 DEGREE ARTICULATION (WITH RESPECT TO ORBITER)
IN Y Z PLANE

BOOM MODELED AS A FLEXIBLE BODY
USING MODAL DEGREES OF FREEDOM

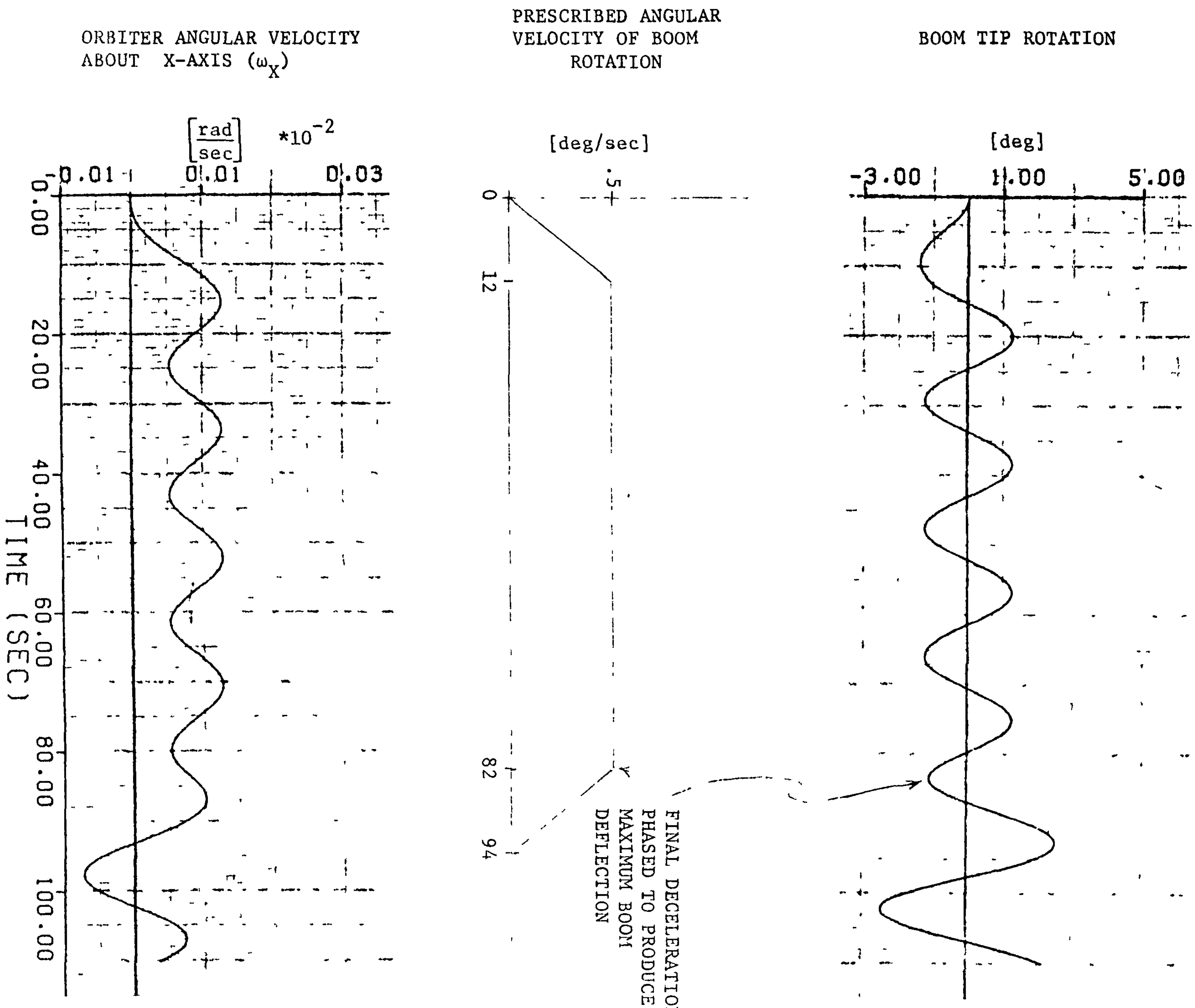
PRESCRIBED ROTATION TIME HISTORY
$\theta(t)$ AT BASE OF BOOM

θ

Z Y X

ORBITER MODELED AS RIGID BODY
WITH FULL 6 DEGREES OF FREEDOM

Figure 2.10



SIMULATION RESPONSE

Figure 2.11

Table 2.9

Gimbaled Platform Mounted Instruments

Electrostatic Analyzers
Magnetic Analyzers & Solid State Detectors
Total Energy Detectors
TV System
Photometers (15)
Individual Experiment Accommodations
Ion Mass Spectrometer
Neutral Mass Spectrometer
Ambient Plasma Diagnostic Package
Camera

Additional optical equipment (spectrometers, interferometer, LIDAR) has been requested for some experiments and for possible atmospheric observations These will be discussed in Part 3 of this report.

2.6 SUBSATELLITE REQUIREMENTS

Although a significant number of experiments can be performed without the benefit of subsatellites, the addition of subsatellites greatly enhances not only the number of experiments that can be performed, but also the depth to which most experiments may be carried Subsatellites broaden the spatial domain over which experiments may be carried out, and the increased distance also increases the time available for performing experiments. With subsatellites it will be possible to study characteristics of long wavelength plasma waves and to perform remote studies such as magnetic conjugate point investigations which could not be performed without these systems.

Based on candidate experimenter requests the list of requirements for a shuttle launched subsatellite is a rather extensive one. Table 2.10 summarizes this list.

Table 2.10

Subsatellite Requirements

Propulsion and Attitude Control

Maneuverable or free flying
Launch & recovery
Command and control (PPEPL)

Experiment Payload

Example: Plasma analyzers, mass spectrometers, E,B field sensors, energetic particle detectors, wide angle and narrow angle cameras and photometers, electron beam, ion guns, etc.

Subsatellite Weight

Minimum 500 to 1000 lb for a 50 to 100 lb payload

Telemetry Requirements

Wideband, versatile, covering a bandwidth 0.01 Hz to 100 MHz.
Storage requriements.

These subsatellites or tethered platforms will generally require many passive diagnostic sensors. Although the typical payload may be a very comprehensive one, the instrument costs should be much less than the comparable costs for an unmanned spacecraft payload. The equipment will have to operate for several hours or days instead of for several years Moreover, in many cases it should be possible to operate the subsatellite on batteries rather than with an expensive solar array power system.

Table 2.11 depicts three alternative power requirements for a shuttle launched subsatellite, assuming a total lifetime of six days. The weights and power for a subsatellite under alternative A (60 lb of batteries) are given in Table 2.12. The 146 pounds of scientific instrumentation suggested for this subsatellite along with the subsystem requirements is indicated in Table 2.13.

Table 2.11

Power and Electrical Integration

POWER REQUIREMENTS: 100 watts nominal

DUTY CYCLE: Alternative A. 12 hours/day for 3 days at 100 watts (3,600 watt-hours)
24 hours/day for 6 days at 2 watts (288 watt-hours)

Alternative B 24 hours/day for 6 days at 100 watts (15,000 watt-hours)

Alternative C 24 hours/day for 30 days at 100 watts (75,000 watt-hours)

POWER SUBSYSTEM: Battery will yield ∿50 watt-hours/lb (not rechargeable)

Alternative A: ∿80 lb batteries

Alternative B: ∿300 lb batteries

Alternative C ∿1500 lb batteries

Body mounted solar array — 23 ft^2, output at 1 AU 85 watts

Equipment converter 70% efficiency
Command distribution 3.5 lb
Standard cabling

Table 2.12

Weights and Power

Item	Pounds	Item	Watts
Communications	10	Transmitter	10 (25 max)
Data Handling	12	Tape Recorders	12
Battery	80	Receiver	2
Attitude Control	50	Decoder	1
Electrical Distribution	15	Orientation	1
Structure	100	DTU	3
Thermal	16	PCU	4
Scientific Experiments	146	Experiments	65
Total	429	Total	98

Table 2 13

TYPICAL PAYLOAD FOR A SUBSATELLITE OR TETHERED PLATFORM

Instrument	Weight (lb)	Volume (ft^3)	Power (watts)	Data Requirements	Orientation Pointing	Orientation Stability	Field of View
Electrostatic Probe	8	0 3	3	100 k bits/sec	1°	1°/min	120°
Planar Trap	8	0.3	3	100 k bits/sec	0.5°	0.5°/min	20°
Hemispherical Analyzer	8	0 3	4	300 k bits/sec	1°	0.5°/min	$\pi/4$
Spherical Ion Probe	8	0 3	4	100 k bits/sec	1°	0.5°/min	4π
RF Spectrometer	8	0.3	5	400 k bits/sec	±1°	1°/min	$>2\pi$
Quadrupole Spectrometer	12	0.5	5	400 k bits/sec	5°	1°/min	2π
3 Axis Fluxgate Magnetometer	8	0 3	3	3000 bits/sec	0.5°	0.5°/min	NA
Rubidium Magnetometer	10	0.4	5	400 bits/sec			
Search Coil	8	0 3	3	100 kHz broad band	0 5°	0.5°/min	NA
E-Field Meter	8	0.3	3	2 MHz broad band	1°	0.5°/min	4π
Image Vidicon	23	0 8	10	6 M bits/sec	0.5°	0 5°/min	±20°
Photometers (6)	8	0 75	3	18 k bits/sec	0 5°	0.5°/min	±20°
VLF Receiver	10	1 0	4	100 kHz broad band	2°	1°/min	--
RF Receiver	7	0.3	4	100 k bits/sec	2°	1°/min	--
Charged Particle Analyzer	6	0 3	3	600 k bits/sec	2°	1°/min	±10°
Annihilation Rad. Det.	6	0 5	3	1000 bits/sec	2°	1°/min	±45°

Two main types of subsatellites have been considered for supplying the basic requirements of the experiments—small and simple passive platforms, and more ambitious active and controllable subsatellites.

The small subsatellites can be simple diagnostic platforms which are launched in the magnetosphere from the Shuttle to provide continuous remote data on plasma parameters. The active experiments performed from the PPEPL will then take advantage of the location of these subsatellites in obtaining parametric data.

A calculation of the orbit of a passive subsatellite released from the shuttle showed that a reasonable series of passes close to the shuttle can be attained. Table 2.14 summarizes the assumptions and results in this calculation. Figure 2.12 shows the trajectories of the passive vehicle relative to the shuttle located at the origin.

Table 2 14

Subsatellite Launch from Shuttle

ASSUMPTIONS

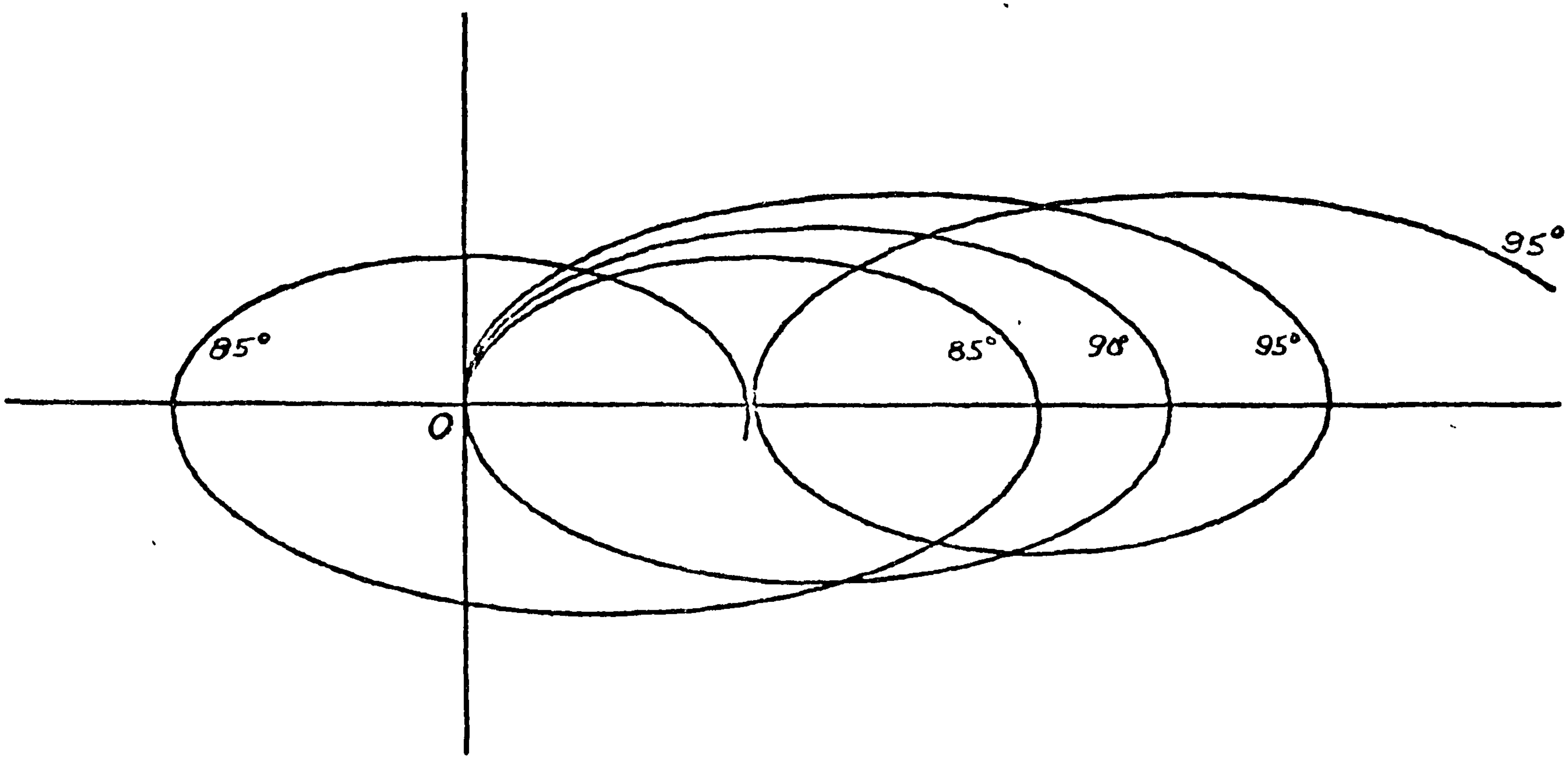
- Shuttle in circular 300 n. mi orbit
- Point mass earth
- No atmospheric drag
- Single impulse injection

RESULTS

- Time-distance plot scales linearly with initial ΔV
- Relative subsatellite trajectory strongly dependent on initial injection angle
- Radial injection: Repeating intersecting ellipse, i.e., no secular motion.

  Major ellipse axis of 0 66 miles per ft/sec injection velocity.
- Near radial injection—subsatellite can orbit shuttle many times
- Proper choice of initial conditions and timing can minimize shuttle motion for recovery
- Injection velocity precision of ±10% and angle precision of ±1° readily feasible

TRAJECTORIES OF PASSIVE SUBSATELLITE EJECTED FROM SHUTTLE



TRAJECTORIES SHOWN ARE FOR INJECTION ANGLES OF 85°, 90° and 95° NOTE THAT WITH AN 85° INJECTION ANGLE THE SUBSATELLITE WILL ORBIT THE SHUTTLE TWICE

Figure 2.12

The angles represent the injection direction relative to the orbiter velocity which is toward the left in the figure. Note that with a 90° injection angle the satellite will return to the orbiter after one orbiter revolution about the earth;with injection angles of less than 90° the satellite will move ahead of the orbiter; with angles of more than 90° the satellite will move behind the orbiter sampling the wake further and further back.

Controllable subsatellites (perhaps based on the Atmospheric Explorer spacecraft) can also be deployed from the PPEPL and they can be maneuvered to the precise locations called for by the particular experiments. This type of platform may also be used to define the spatial extent of phenomena and varying boundary conditions of importance. Aside from free-flying subsatellites, it is also contemplated that remote tethered platforms can be deployed.

The characteristics of a typical active subsatellite (Atmospheric Explorer) are summarized in Table 2 15.

Table 2.15

Active (Maneuverable) Subsatellite

BASELINE UNIT	ATMOSPHERIC EXPLORER
S/C weight.	560 kg
Payload weight·	100 kg
Energy.	4000 watt-min
Att. control:	1.0°
Orbit adjust:	2000 ft/sec
Data rate:	∿130 kbps

Part 3

CONCEPTUAL LABORATORY DESIGN

3.1 INTRODUCTION

The preliminary considerations in laying out the PPEPL are summarized in Table 3.1.

Table 3.1

Laboratory Layout Considerations

- Sortie Can Configuration
  - -In Shuttle Bay
  - -Deployed Module
- Boom, Subsatellite Tradeoffs
- Pallet or Surface Mounted
- Choice of Experiment Area
  - -Dedicated to One Area
  - -Multiple Area Representation
  - -Complete (All Areas)
  - -Time Phasing
- PPEPL vs Atmospheric Sciences

The last item in the table above refers to the inclusion or absence of an atmospheric science observatory as part of the laboratory, or whether such an observatory should be a separate laboratory. For the most part, our laboratory conceptual design did not satisfy the requirements for an atmospheric observatory. However, the whole laboratory was designed against a requirement of maximum flexibility and growth potential. Thus the atmospheric requirements can be included in the laboratory described here with only moderate changes in the configuration. A first iteration of such a combined facility will be described at the end of this part of the report.

3.2 BOOM AND SUBSATELLITE REQUIREMENTS

The feasibility of subsatellites and booms for remote deployment of instruments, as well as the effect of different combinations of these deployment devices, was subjected to careful analysis. Figure 3.1 shows the results of this analysis. The abscissa indicates the type of deployment mechanism used, i.e., without or with a subsatellite, and either one, two, or three booms. The ordinate is the number of experiments that can be satisfied with a given deployment configuration. The curves represent the percentage of objectives satisfied by the experiments. As an example, the 60 percent curve represents a deployment scheme which satisfies 60 percent of the objectives of each experiment. Thus some 113 experiments can have 60 percent of their objectives satisfied with two booms, while the addition of a subsatellite brings the total to 160 experiments. Since no weight was given to the importance of any objective, the statistics themselves can be misleading However, for 100 percent fulfillment, the number of experiments jumps from 50 to 125 when a subsatellite is added. It was for this reason that the basic laboratory was defined to include a subsatellite.

3.3 OPTICAL REQUIREMENTS

A similar analysis was performed for optical equipment as shown in Figure 3.2. Here, as we go to the right, the number of instruments is the sum of all those instruments to the left. The basic laboratory complement is defined as a film camera, photometer array, and TV imaging system. Spectrometers are included for the growth laboratory. As we will see below, the optical equipment list may well be significantly extended should atmospheric observations become a part of the PPEPL.

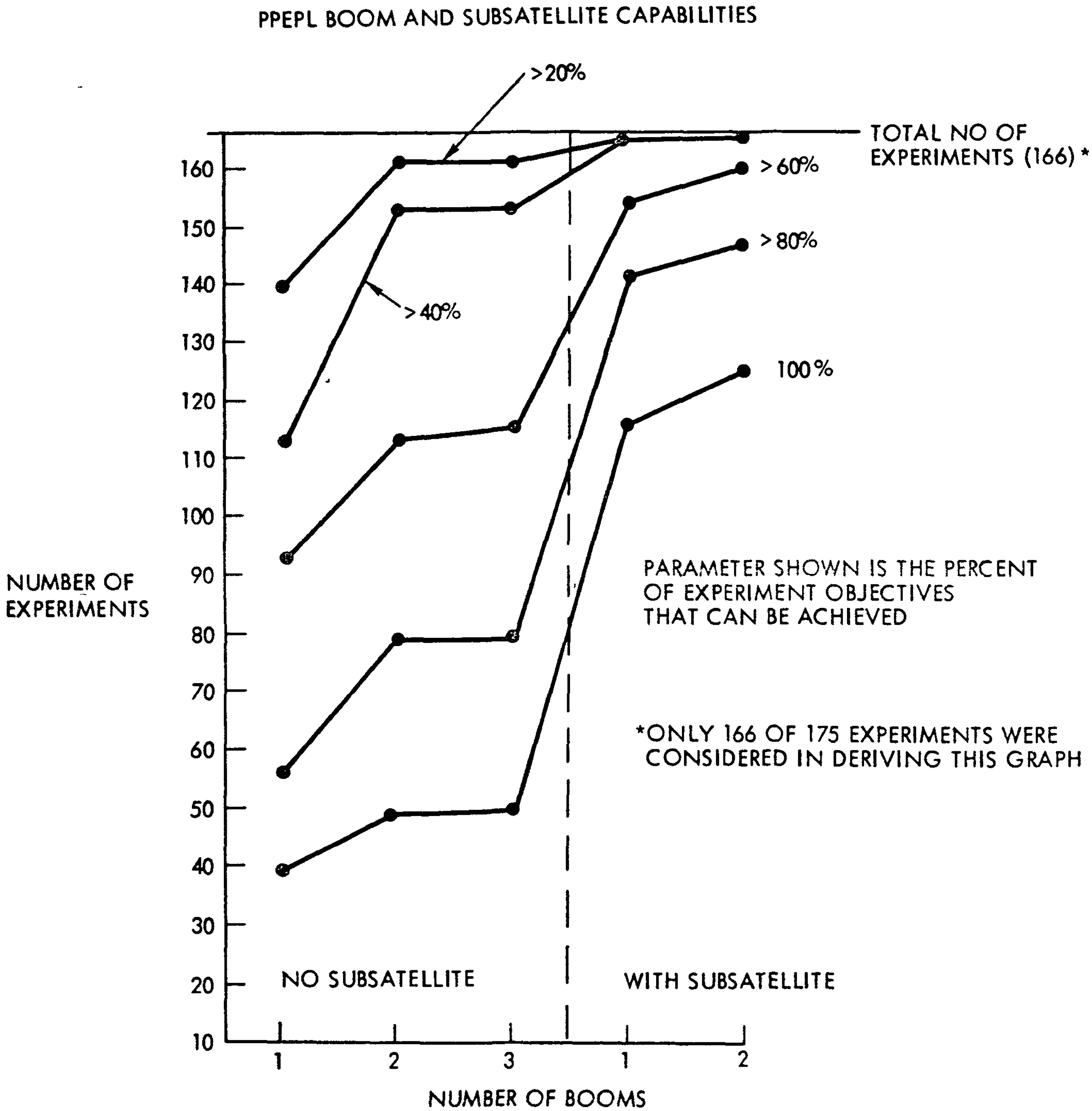

PPEPL BOOM AND SUBSATELLITE CAPABILITIES
>20%
TOTAL NO OF EXPERIMENTS (166) *
>60%
>80%
>40%
100%
NUMBER OF EXPERIMENTS
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
PARAMETER SHOWN IS THE PERCENT OF EXPERIMENT OBJECTIVES THAT CAN BE ACHIEVED
*ONLY 166 OF 175 EXPERIMENTS WERE CONSIDERED IN DERIVING THIS GRAPH
NO SUBSATELLITE
WITH SUBSATELLITE
1
2
3
1
2
NUMBER OF BOOMS

Figure 3 1

PPEPL OPTICAL REQUIREMENT

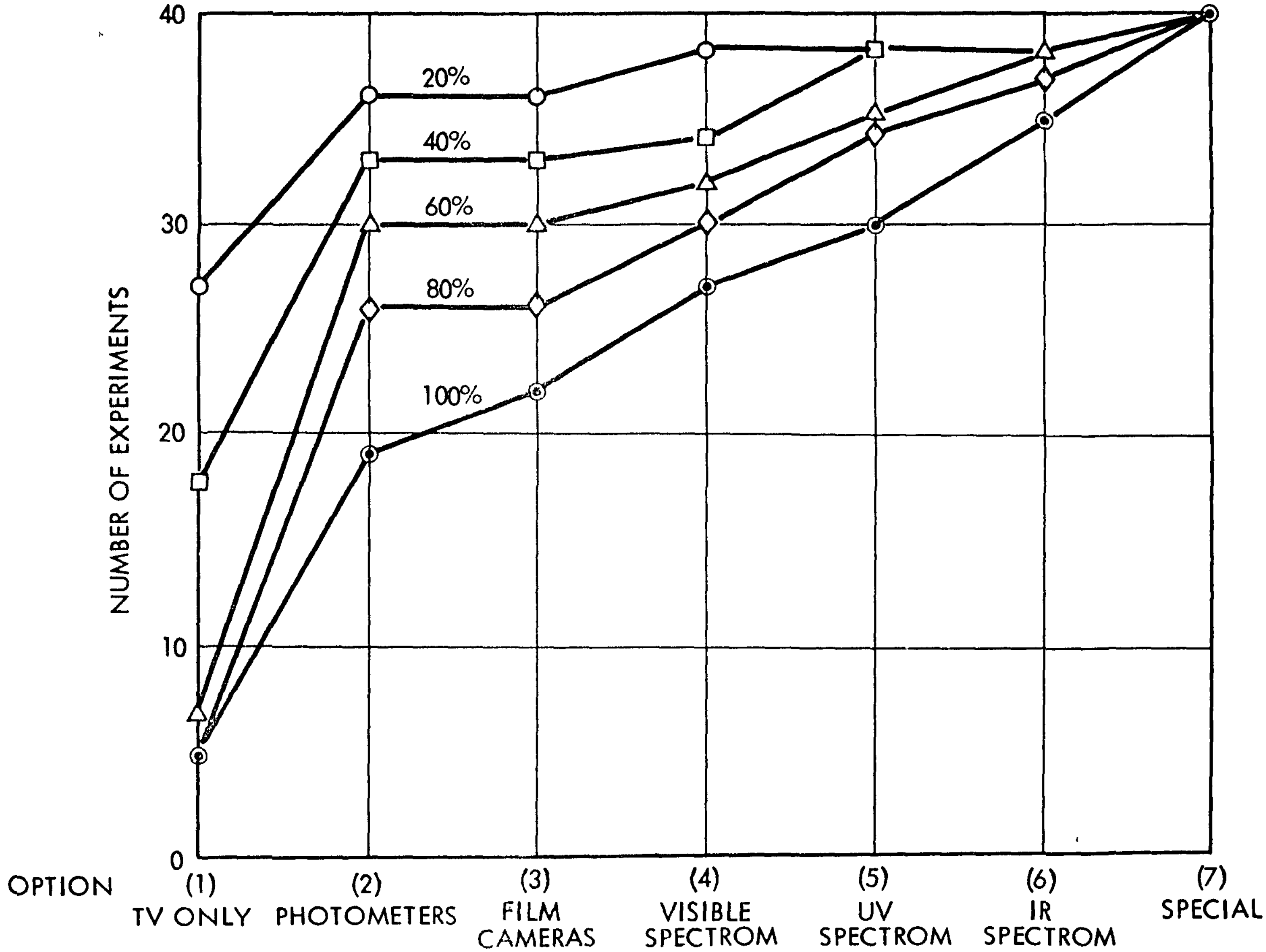


Figure 3.2

3.4 LABORATORY DEFINITION

The instrumentation derived from the questionnaire was used to develop three labs of increasing complexity and completeness. In the current atmosphere of ever shrinking space budgets, the primary criterion in defining the three labs was program cost. Based on this criterion, we designed an early lab with less than the full complement of instruments and which does not require the development of any new items. This early version of the lab, despite its limitations, represents an extensive and even ambitious experiment porgram. However, the lab would have been more functional if we could have included items that required development.

The three versions of the PPEPL were defined under the following guidelines·

BASIC LABORATORY

- Low cost
- No extensive development
- Maximum use of commercial equipment
- Broad capability

AUSTERE VERSION

- Minimum cost
- No subsatellites
- Fewer launches

GROWTH LABORATORY

- Development costs not well defined
- Increased capability of basic lab system
- Satisfied all Shuttle experiment requirements

The versions are a natural extension of one another in that the laboratory design itself would not change with increasingly sophisticated instrumentation. All have been designed to fit within the current design capabilities of the Shuttle vehicle. As designed, the Shuttle's weight, power, volume, etc., are adequate to accommodate a quite complex and complete space laboratory capable of carrying out a wide variety of investigations

The following tables (Tables 3.2 through 3.6) describe the features of each of the laboratory versions, summarize the limitations of the austere laboratory, and define the ground rules in more detail for developing the basic and growth versions.

Table 3.2

Summary of Austere Laboratory Features

- Two 50-meter booms, no subsatellites
- No cryogenic systems
- Photometer array on gimbaled platform, no spectrometers
- Standardized accelerators

  30-50 keV protons, up to one ampere (on pallet)
  10-50 keV electrons, up to one ampere (on pallet)
  5-20 eV electron gun (on boom)
  High power MPD plasma accelerator (on pallet)

- High powered transmitter only for f $\gtrsim 10^5$ Hz, 1000' dipole elements
- Low power transmitters for VLF and below, boom-to-boom transmissions
- Shaped charges, barium canisters will be carried if safety considerations permit
- Complete diagnostic packages

Table 3.3

EXPERIMENT LIMITATIONS WITH AUSTERE LABORATORY

NO SUBSATELLITE	REQUIRED FOR SPIN MODULATION, REMOTE SENSING OF TRACERS: EP-1, EP-4, EP-18, EP-20.
	REQUIRED TO SEPARATE SPACE-TIME VARIATIONS: BP-4, BP-11, WP-2, WP-4.
	REQUIRED TO STUDY LONG WAVELENGTH WAVES. WP-12, WC-15.
	OTHER ENTRIES AFFECTED. WS-3(DRAG), PD-10, PD-12, WC-34, BP-3 (SUB-SATELLITE SYSTEMS)
	GENERAL MANY OTHERS DESIRE SUB-SATELLITE, BUT PARTIAL EXPERIMENT CAN BE CONDUCTED WITH AUSTERE LAB., ROCKETS, GROUND-BASED DATA
NO CRYOGENIC SYSTEM	LARGE SUPERCONDUCTING MAGNET IS REQUIRED FOR WS-8, WS-17, WS-31, PP-3, PP-4, PP-15, PP-7, PP-6.
	CRYOGENIC MAGNETOMETER REQUESTED FOR WC-6, WC-17.
NO SPECTROMETERS	DOESN'T APPEAR CRUCIAL, SEVEN EXPERIMENTERS REQUEST SPECTROMETERS, BUT ∿ 80 PERCENT OF OBJECTIVES CAN PROBABLY BE ACHIEVED WITH PHOTOMETERS
NO HIGH POWERED ULF, ELF, VLF TRANSMITTERS	BEAMS MAY SUCCEED IN GENERATING EM WAVES, ES WAVES, NO PROBLEM.
	SMALL ROOM-TO-ROOM SEPARATION AND LOW POWER MEANS THAT EM WAVE EXPERIMENTS WILL GIVE NEAR FIELD OR RESONANCE INFORMATION ONLY
	LIMITATION MAINLY AFFECTS WP-12, WC-6, WC-15, WC-7 (PERHAPS WC-1, WC-35).
OTHER LIMITATIONS	MM-3, MM-9, NO INFORMATION ON METHOD OR FEASIBILITY.
	WS-26, LASER REFLECTION IN WAKE APPARENTLY NOT FEASIBLE
	EP-12, POSITRON SOURCE WILL NOT BE CARRIED (ROCKET LAUNCHED?)
	WS-24, PD-3, RAMAN SCATTERING DEVICE WILL NOT BE CARRIED (NOT PLASMA PHYSICS)

Table 3.4

Plasma Physics and Environmental Perturbation Laboratory

Basic and Growth Version

Ground Rules

Definition	Implication
BASIC VERSION	
Add capability and experiments that don't require extensive development. Add subsatellites, new instruments, and improved instruments.	Substantial increase in scientific achievement with a concurrent increase in cost. Costs are well defined since instruments have been developed. Assume commercial equipment can be adapted to module interior.
GROWTH VERSION	
Capability to perform experiments that require extensive development incorporated into the growth version.	Parallel studies required to prove feasibility and undertake development The costs are not as well defined.

Table 3.5

Summary of Basic Laboratory Features

- Two 50-meter booms, two passive subsatellites
- No cryogenic systems
- Photometer array on gimbaled platform, no spectrometers
- Standardized accelerators

  30-50 keV protons, up to one ampere (on pallet)
  10-50 keV electrons, up to one ampere (on pallet)
  5-20 eV electron gun (on boom)
  High power MPD plasma accelerator (on pallet)
- High powered transmitter only for f $\gtrsim 10^5$ Hz, 1000' dipole elements
- Low power transmitters for VLF and below, boom-to-boom transmissions
- Shaped charges and barium canisters will be carried if safety considerations permit
- Complete diagnostic packages

Table 3.6

Summary of Growth Lab Features

Controlled multisatellites

Improved spectrometer array on gimbaled platform

Introduce large B field superconducting magnet

Boom to satellite transmission

Satellite-to-satellite transmission

1 MeV, multigun array, electron accelerator

1 MeV, proton and ion accelerator

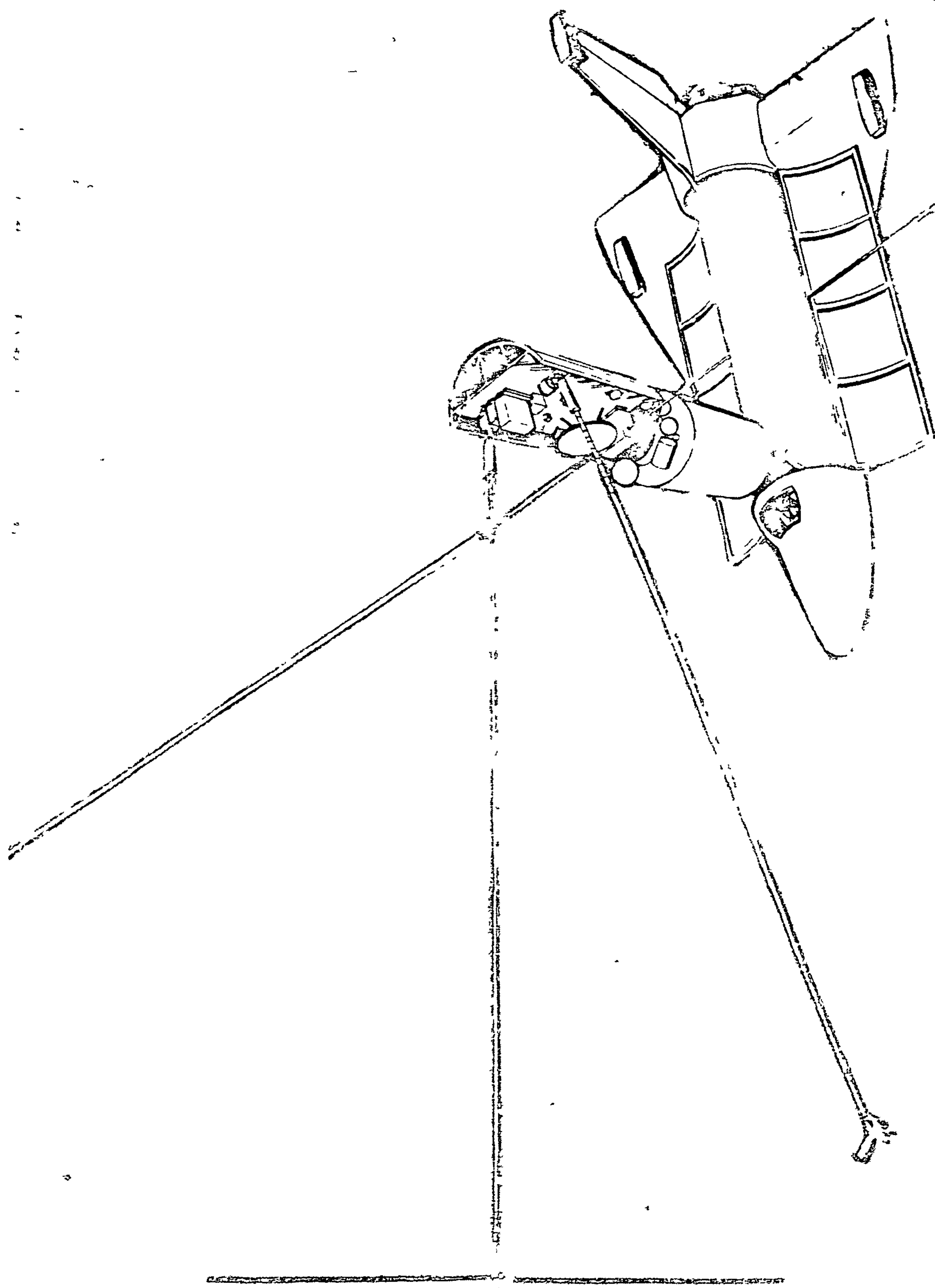
Plasma accelerator for different species
- Higher exhaust velocities (10^7 cm/sec)
- Increased power

Advanced release experiment. Massive metals with ions in the keV range

High powered transmitter for $f < 10^5$ Hz

3.5 LABORATORY CHARACTERISTICS

The basic PPEPL concept, summarized in Table 3.5, is shown deployed from the shuttle during mission operations in Figure 3.3. The out-of-bay configuration, one of the options planned for the Shuttle, was chosen as best meeting the requirements of the laboratory for broad pointing and viewing capability and for minimum electromagnetic interference. In this configuration the effective length and maneuverability of the booms is also greater than for an in-bay configuration. Although this deployment mode is extremely beneficial for PPEPL, it is not a mandatory requirement, it is possible to redesign the pallet package for the undeployed mode. The Sortie Lab is accessible to the Shuttle through a pressurized tunnel, and the far end of the pallet is about fifty-eight feet above the Shuttle bay in the deployed mode.



Two 50-meter booms are shown deployed in Figure 3.3 along with the 1000-foot VLF/RF transmitting antenna. One of the booms (the upper one in Figure 3.3) is the passive, or diagnostic boom. Two subsidiary 5-meter booms are deployed from the platform for isolation of electric and magnetic fields from the extensive instrumentation on the platform itself. A 100-foot dipole receiving antenna is also deployed from the platform. The second 50-meter boom acts as a perturbation source. As such, balloons or acoustic wave generators, for example, would be deployed from this boom and the effects measured on the second, or diagnostic, boom.

The layout of the laboratory is shown in Figure 3.4. Labels indicate the major equipment and instrumentation. Mounted on the far end of the pallet are high-power, electron-ion accelerators complete with power supply The guns themselves are of several types, but it is contemplated that they will operate from a common power supply. On the opposite end of the pallet nearest the Sortie Lab is mounted a variable transmitter and power supply with associated dipole antenna. The dipole antenna may be extended to about 1000 feet per element once the PPEPL is deployed. (The Wave-Particle Interaction Working Group suggested that for high frequency wave experiments it might be desirable to include other types of antennas, such as dishes, on the pallet.)

About half-way between the antenna and the electron-ion beam guns, a gimbaled platform approximately eight feet in diameter is mounted. This gimbaled platform contains optical and particle detectors requiring pointing. These sensors are used for a number of experiments, especially those in the areas of beam-plasma interactions, magnetospheric modifications, and energetic particles and tracer experiments.

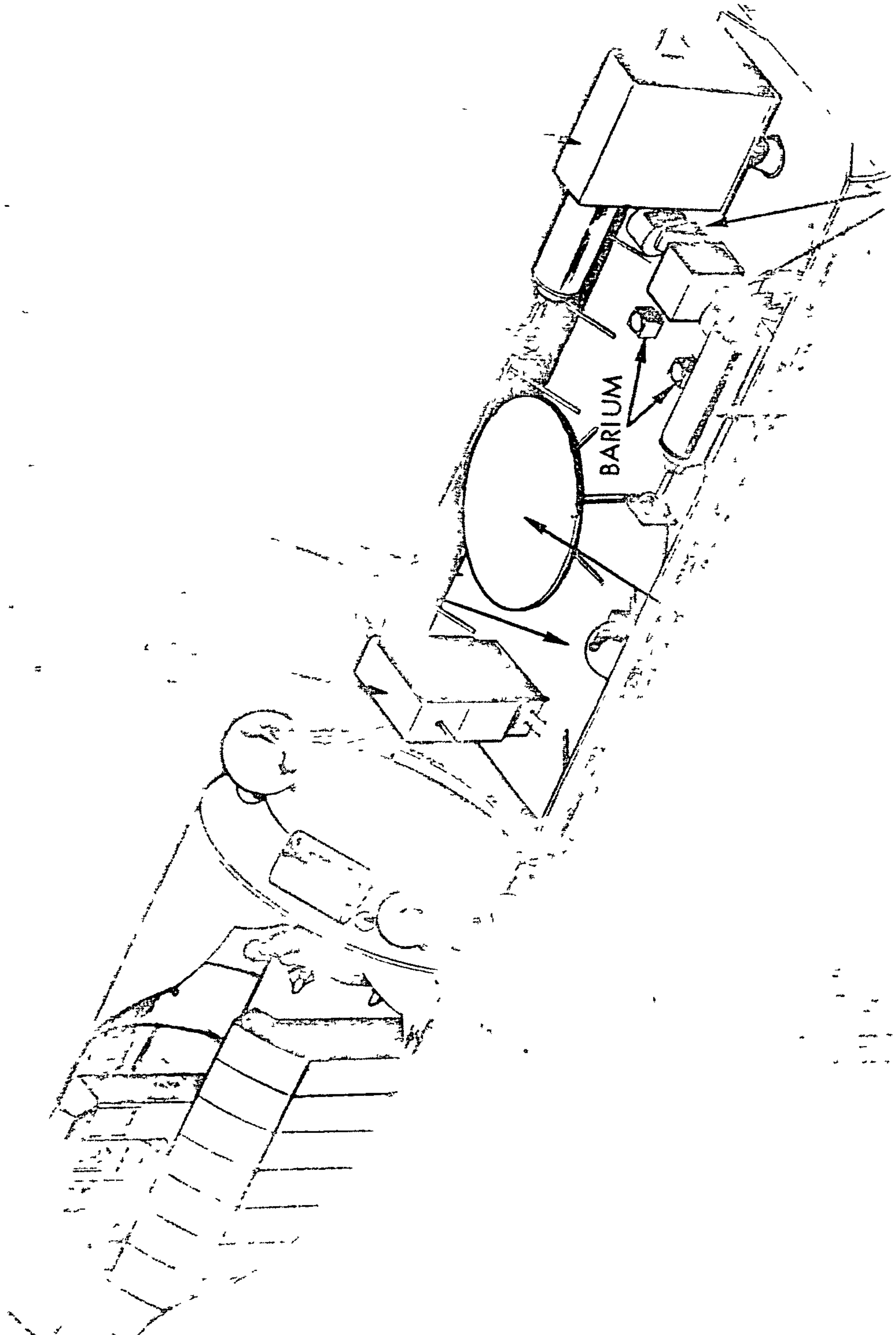


Figure 3 4

The pallet provides sufficient area to accommodate other experiment items. For example, cannisters containing lithium, barium, or other chemicals may be mounted on the pallet and ejected to carry out ionospheric wind studies, field line tracing, and electric field investigations. In a similar manner, cannisters containing inflatable "wake bodies" may also be ejected, as may maneuverable subsatellites (such as the Atmospheric Explorer). It can be seen that with the concept illustrated in Figure 3.4, considerable space for growth is provided.

Inside the pressurized Sortie Lab are located the control and display consoles for the instruments, booms, subsatellites, transmitters and receivers for the RF and VLF experiments, electron and ion beams. In addition, a computer, spectrum analyzers for near real time data evaluation, additional power supplies, general work areas, and recorders are also located in this module.

3.6 DETAILED DESCRIPTION OF LONG BOOM ASSEMBLIES

The present conceptual design is based on the use of two retractable 50-meter booms of the Astromast variety, mounted on swivel platforms so that the extensions and relative orientations may be controlled from within the pressurized laboratory. Figure 3.5 is a photograph of a 1/50 scale model of PPEPL, with the pallet-mounted booms deployed to 16 meters. Boom number one (the left side of Figure 3.5) is the passive or diagnostic boom, and it contains a full array of equipment to diagnose the ambient plasma characteristics (density, temperature, composition, suprathermal particle population) as well as the ambient vector dc magnetic field, one axis of the dc electric field, and the electric and magnetic components of local plasma waves. A possible configuration is shown in Figure 3.6. Two small (5-meter) retractable subbooms are used

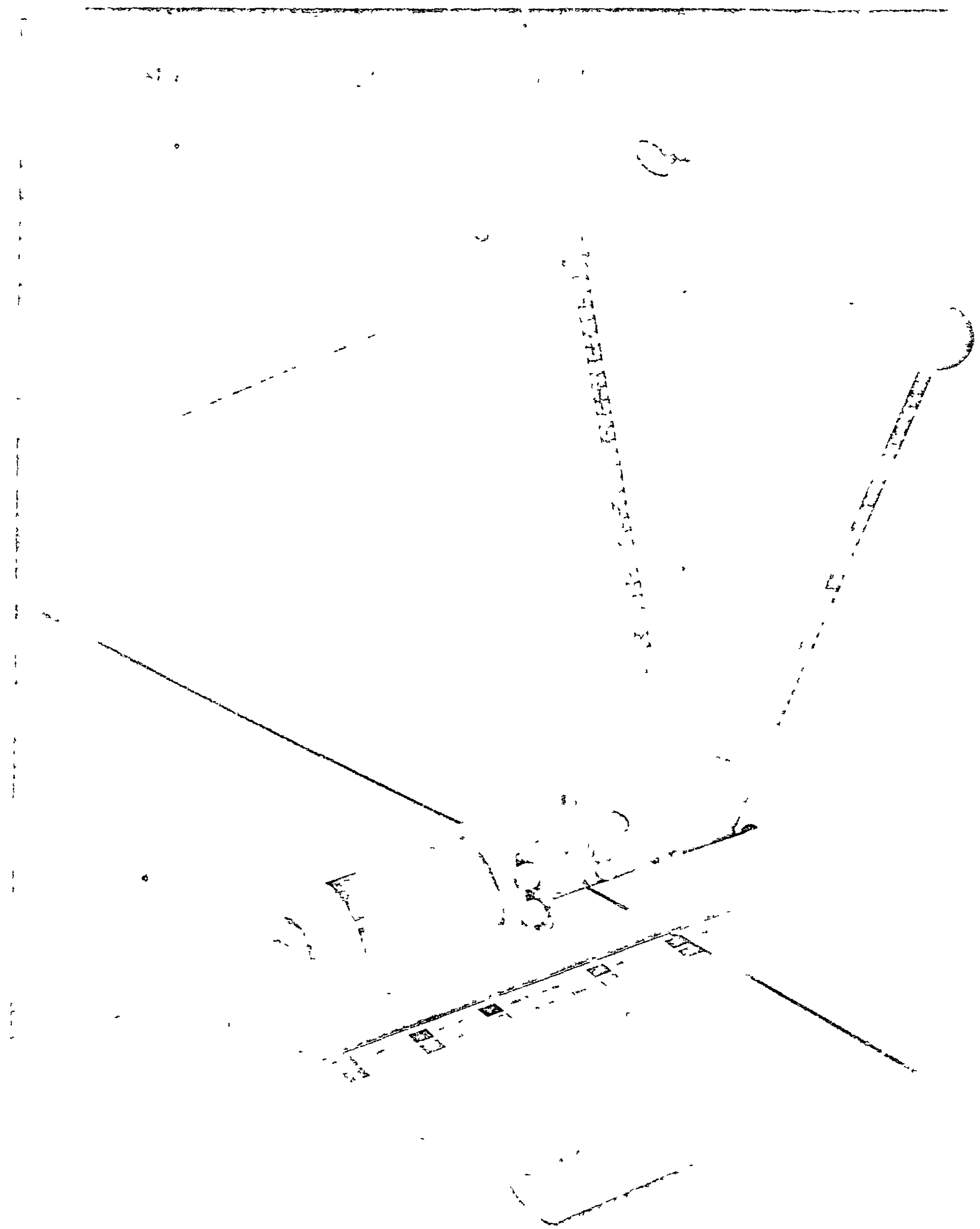
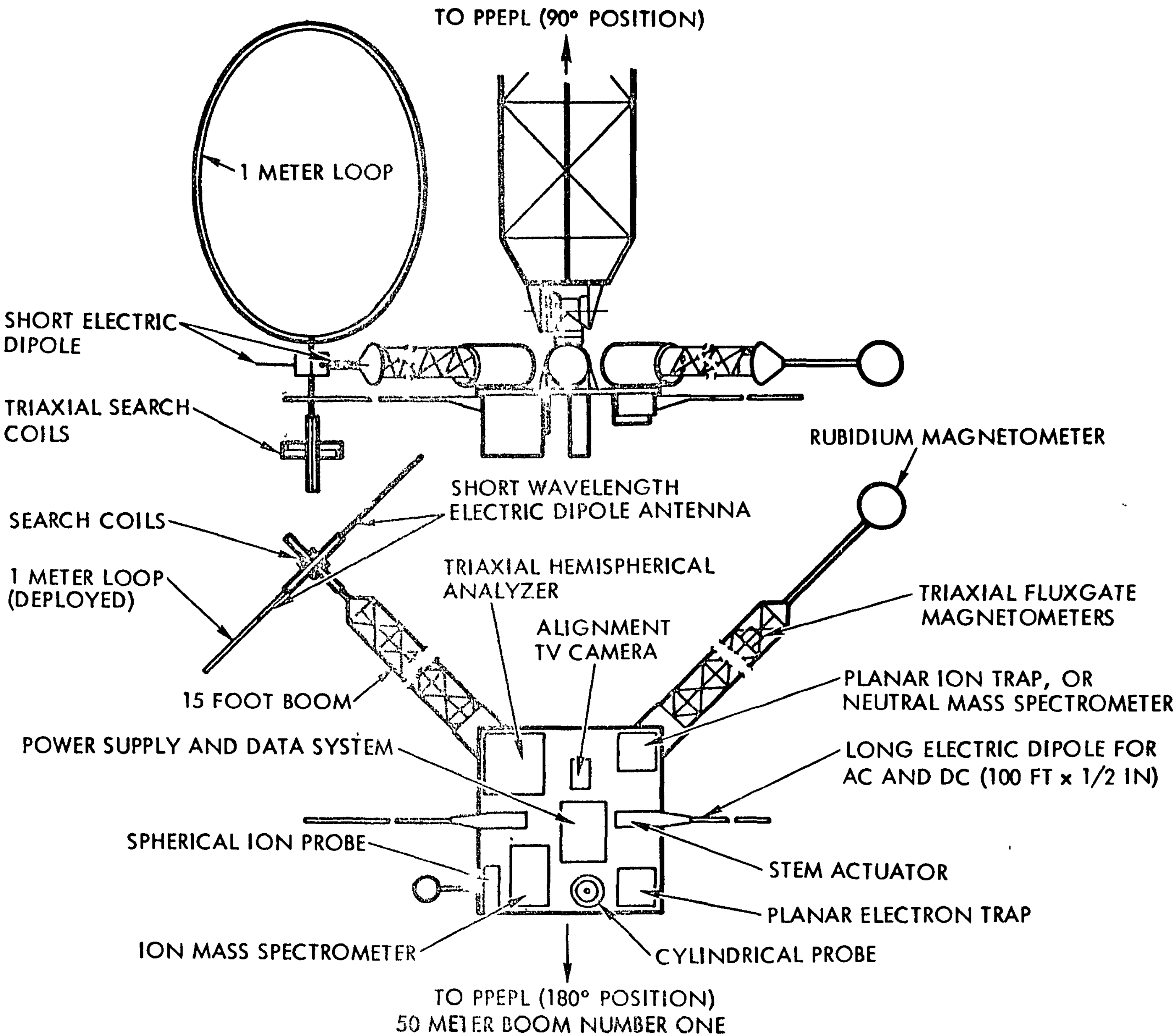


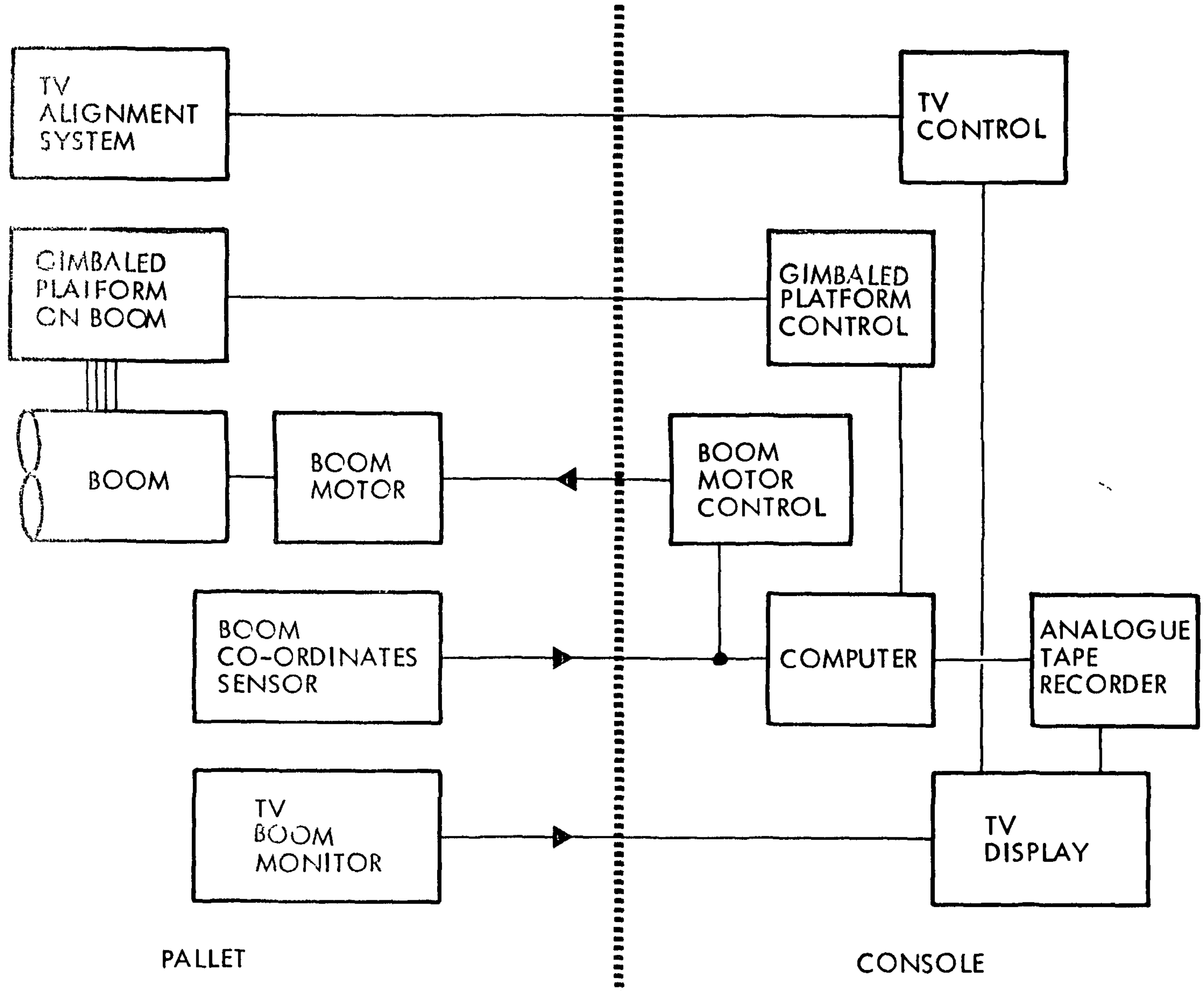
Figure 3.5


TO PPEPL (90° POSITION)
1 METER LOOP
SHORT ELECTRIC DIPOLE
TRIAXIAL SEARCH COILS
RUBIDIUM MAGNETOMETER
SHORT WAVELENGTH ELECTRIC DIPOLE ANTENNA
SEARCH COILS
1 METER LOOP (DEPLOYED)
TRIAXIAL HEMISPHERICAL ANALYZER
TRIAXIAL FLUXGATE MAGNETOMETERS
ALIGNMENT TV CAMERA
15 FOOT BOOM
PLANAR ION TRAP, OR NEUTRAL MASS SPECTROMETER
POWER SUPPLY AND DATA SYSTEM
LONG ELECTRIC DIPOLE FOR AC AND DC (100 FT x 1/2 IN)
SPHERICAL ION PROBE
STEM ACTUATOR
PLANAR ELECTRON TRAP
ION MASS SPECTROMETER
CYLINDRICAL PROBE
TO PPEPL (180° POSITION)
50 METER BOOM NUMBER ONE

to remove the field-measuring sensors from the particle detectors in order to minimize EMC and magnetic contamination. Some items in this figure require additional explanation. (a) the one-meter loop is supposed to be a Mylar balloon of the type flown on several OGO spacecraft. This loop is inflated by a gas bottle and it is ejected before the boom package is retracted, (b) the rubidium magnetometer is presently included because a number of candidate experimenters requested a continuous and accurate measure of the local electron gyrofrequency, primarily in order to tune the transmitter for various RF sounding experiments, (c) the alignment TV camera will be used to point the instruments on boom #1 toward the active or exciting elements on the second boom or on the pallet, (d) in order to minimize cabling along the retractable 50-meter boom it appears expedient to have the power supply and an encoder-multiplexer mounted at the end of the boom. A block diagram of the control system for this boom is shown in Figure 3.7. The left side of the figure shows the pallet mounted equipment, the right side the equipment necessary for control and display of boom parameters from within the pressurized module.

The second boom (see the right side of Figure 3.5) is the active one, and it is planned that for any given flight, core equipment will be selected to carry out the designated experiments, or experiment-unique equipment will be provided by the investigator. A possible configuration for boom number two would contain (a) a low energy (5-20 eV) electron gun to measure E parallel to B and to study low energy beam-plasma streaming instabilities, (b) an electrostatic plasma wave generator for boom-to-boom transmission experiments; (c) various targets for wake-sheath studies, such as the large sphere shown in Figure 3.6. These targets might be balloons with variable shapes and surface materials, capable of being biased electrically with respect to the plasma.

BOOM CONTROL SYSTEM



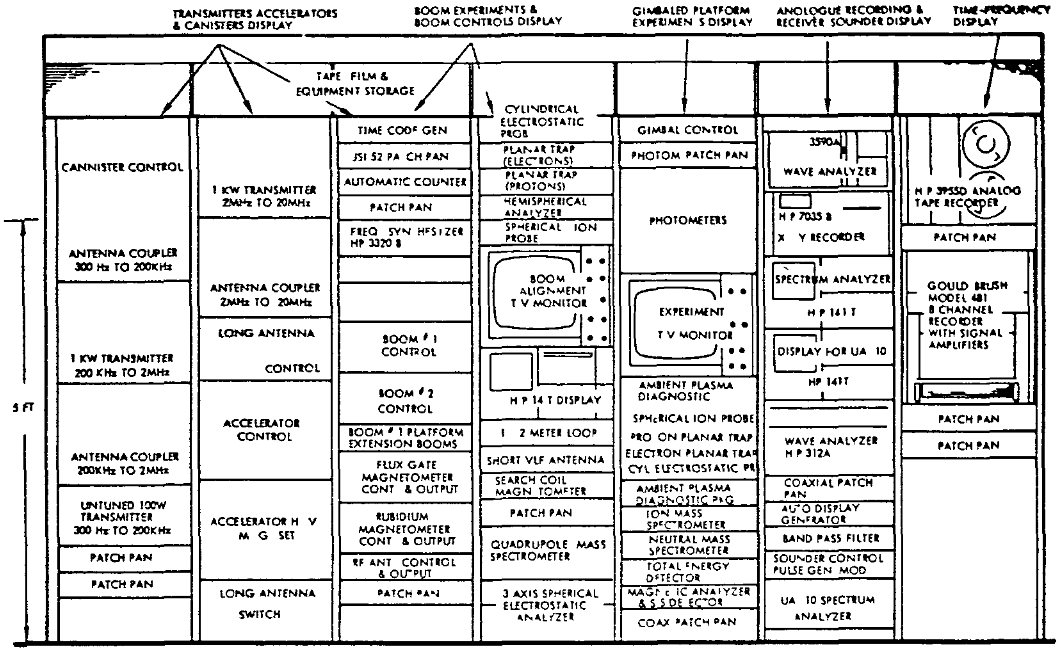
Figure

3.7 TELEMETRY REQUIREMENTS

The Plasma Physics and Environmental Perturbation Laboratory opens a new era in spacecraft data management. The laboratory will be required to record large amounts of passive diagnostic data per day, and it will also be required to record source characteristics of the planned perturbations and to provide the user with the appropriate data for correlation. It is expected that most experiments will be programmed; however the intervention and innovation of the experimenter will provide a new dimension in performing experiments in space. Therefore, data formating must be devised to provide a universal reduction capability to users, and to facilitate real time sampling during experiment operations. In addition, the data system will provide a control function for many of the instruments and support systems such as booms, power supplies, subsatellites, etc.

The whole laboratory has been designed with growth potential in mind, and less than half of the possible equipment rack space is utilized in the preliminary interior rack layout as shown in Figure 3.8. However, before the design is completed, much additional control and display equipment will be added to that shown in Figure 3.8, especially in the area of accelerator and subsatellite control. This will take up some of the available space.

The PPEPL interior concept was designed so that one could plan to make only relatively minor manufacturing changes in adapting commercial units to the PPEPL. Almost all display units chosen have commercially available prototypes, and the designs of the control units reflect standard earth laboratory equipment. At present the quality assurance and reliability requirements for experiment equipment on the shuttle are not defined. The goal, however, is


TRANSMITTERS ACCELERATORS & CANISTERS DISPLAY
BOOM EXPERIMENTS & BOOM CONTROLS DISPLAY
GIMBALED PLATFORM EXPERIMENTS DISPLAY
ANOLOGUE RECORDING & RECEIVER SOUNDER DISPLAY
TIME-FREQUENCY DISPLAY
TAPE FILM & EQUIPMENT STORAGE
CANNISTER CONTROL
ANTENNA COUPLER 300 Hz TO 200KHz
1 KW TRANSMITTER 200 KHz TO 2MHz
ANTENNA COUPLER 200KHz TO 2MHz
UNTUNED 100W TRANSMITTER 300 Hz TO 200KHz
PATCH PAN
PATCH PAN
1 KW TRANSMITTER 2MHz TO 20MHz
ANTENNA COUPLER 2MHz TO 20MHz
LONG ANTENNA CONTROL
ACCELERATOR CONTROL
ACCELERATOR H V M G SET
LONG ANTENNA SWITCH
TIME CODE GEN
AUTOMATIC COUNTER
PATCH PAN
FREQ SYNTHESIZER HP 3320 B
BOOM # 1 CONTROL
BOOM # 2 CONTROL
BOOM # 1 PLATFORM EXTENSION BOOMS
FLUX GATE MAGNETOMETER CONT & OUTPUT
RUBIDIUM MAGNETOMETER CONT & OUTPUT
RF ANT CONTROL & OUTPUT
PATCH PAN
CYLINDRICAL ELECTROSTATIC PROB
PLANAR TRAP (ELECTRONS)
PLANAR TRAP (PROTONS)
HEMISPHERICAL ANALYZER
SPHERICAL ION PROBE
BOOM ALIGNMENT T V MONITOR
H P 141 T DISPLAY
1 2 METER LOOP
SHORT VLF ANTENNA
SEARCH COIL MAGN TOMETER
PATCH PAN
QUADRUPOLE MASS SPECTROMETER
3 AXIS SPHERICAL ELECTROSTATIC ANALYZER
GIMBAL CONTROL
PHOTOM PATCH PAN
PHOTOMETERS
EXPERIMENT T V MONITOR
AMBIENT PLASMA DIAGNOSTIC
SPHERICAL ION PROBE
PRO ON PLANAR TRAP
ELECTRON PLANAR TRAP
CYL ELECTROSTATIC PR
AMBIENT PLASMA DIAGNOSTIC PKG
ION MASS SPECTROMETER
NEUTRAL MASS SPECTROMETER
TOTAL ENERGY DETECTOR
MAGNETIC ANALYZER & S S DETECTOR
COAX PATCH PAN
3590A
WAVE ANALYZER
H P 7035 B
X Y RECORDER
SPECTRUM ANALYZER
H P 141 T
DISPLAY FOR UA 10
HP 141T
WAVE ANALYZER H P 312A
COAXIAL PATCH PAN
AUTO DISPLAY GENERATOR
BAND PASS FILTER
SOUNDER CONTROL PULSE GEN MOD
UA 10 SPECTRUM ANALYZER
H P 3955D ANALOG TAPE RECORDER
PATCH PAN
GOULD BRUSH MODEL 481 8 CHANNEL RECORDER WITH SIGNAL AMPLIFIERS
PATCH PAN
PATCH PAN
5 FT

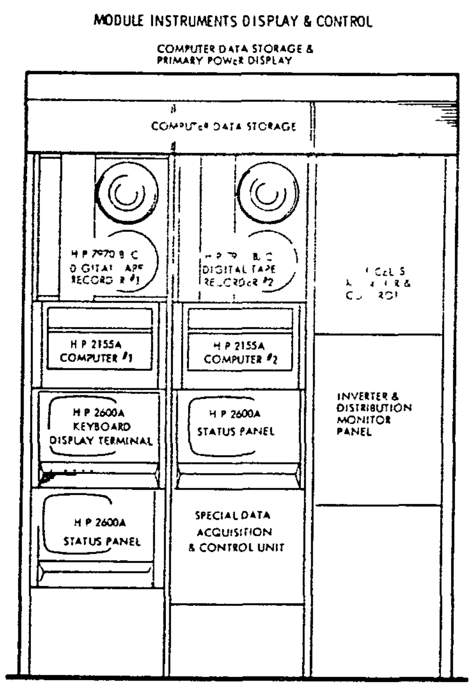

MODULE INSTRUMENTS DISPLAY & CONTROL
COMPUTER DATA STORAGE & PRIMARY POWER DISPLAY
COMPUTER DATA STORAGE
H P 2155A COMPUTER #1
H P 2155A COMPUTER #2
H P 2600A KEYBOARD DISPLAY TERMINAL
H P 2600A STATUS PANEL
INVERTER & DISTRIBUTION MONITOR PANEL
H P 2600A STATUS PANEL
SPECIAL DATA ACQUISITION & CONTROL UNIT

Figure 3.8

to minimize these requirements so that only minor modifications to commercial equipment might be necessary. For example, the removal of sharp corners and use of low outgassing wiring and potting might be the only changes made to many units.

The weight and power requirements for the interior rack mounted equipment are given in Table 3.7. The total operating power requirements cannot, however, be used directly for overall mission requirements All the equipment will never be on simultaneously but the precise complement will depend on the time line of experiments. Thus the power figures only give an indication of idealized peak power requirements. As a further note to Table 3.7 the operating powers given in parentheses are figures based on current standard earth-bound laboratory equipment. There is every reason to believe that lab units will be developed, using new MOS-FET and Liquid Display technology, with substantially reduced power requirements Certainly the growing energy crisis will provide an additional incentive in this direction. Thus the operating powers of Table 3.7 are conservative estimates of projected developments. (Table 2.3 is included again for reference to give overall laboratory requirements in one place.)

Table 3.7

Display and Control Requirements

		Display	Control	Totals
WEIGHT		900 kg	800 kg	1700 kg
POWER.	Standby	80 - 1460	140 W	220 - 1600 W
	Operating	2200 W (5300W)	540 W (730 W)	2740 W (6000 W)
RACK HEIGHT		68 ft	52 ft	120 ft

Instrument Correlation Assumptions

- Computing group common for all instruments
- Each instrument includes its own electronic processing equipment
- No correlations within the instrument list

Table 2.3

INSTRUMENTATION REQUIREMENTS

	WEIGHT	VOLUME	PEAK POWER	DATA
A-ACCELERATORS	1215 kg	4 M^3	to 10 kW	2×10^3 bps
T-TRANSMITTERS	210	0.5	to 10 kW	3×10^2
B-BOOMS	525	1.6	280 W	10^6
G-GIMBALED PLATFORM	126	6.3	210 W	10^6
D-DEPLOYABLE UNITS	820	0.6	--	--
DS-DEPLOYABLE SUBSATELLITE	270	1.6	234 W	2 Mhz, 3×10^5 bps

POINTING: $\pm 0.5°$ to $\pm 1.0°$

3.8 COMBINED PLASMA PHYSICS LABORATORY AND ATMOSPHERIC SCIENCES OBSERVATORY

Study described herein originated with a study for a Plasma Physics and Environmental Perturbation Laboratory (PPEPL) solely devoted to research dealing with the earth's ionized medium. In July of 1973, the U. S. National Academy of Sciences conducted a general study on scientific uses of the space shuttle, and the participants discussed a single sortie lab facility that would combine the requirements of the scientists interested in PPEPL and the requirements of scientists concerned with remote sensing of the atmosphere between 30 and 120 km. In the summer of 1973, some shuttle-sortie lab engineering developments forced a second significant modification in the PPEPL planning, it became apparent that problems associated with shuttle landing weight limits and with center of gravity considerations would restrict the total sortie lab payload weight to about 32,000 pounds, and would restrict the payload bay volume available for the pressurized laboratory and pallet

It appears that a combined sortie laboratory facility for the controlled space and plasma physics experiment area and for the atmospheric science area can readily be configured to fit within the revised shuttle guidelines.

The atmospheric physics requirements do, however, involve a significant expansion of the remote sensing capability planned for the pallet mounted gimbaled platform In the draft of the NAS Summer Study Report the requirements were outlined in terms of instrumentation that would provide

1. Horizon scanning of selected airglow features by high spectral resolution photometers and interferometers (primarily optical and IR range)

2. Vertical passive probing by infrared interferometry to determine the vertical distribution of constituents such as CO_2 and O_3 (1-5 mm, 5-150 mm).

3. Lidar probing of the lower atmosphere (pulses in the UV 2200-2000 Å range).

4. Measurement of the absorption of light in selected spectral regions between the shuttle and a steerable subsatellite.

As noted above, in mid-1973 the NASA and ESRO Shuttle/Spacelab program planners concluded that the overall payload weight and the distribution of equipment would have to be restricted for sortie missions. The top part of Figure 3.9 shows a tentative configuration that provides a suitable location for the center of gravity, assuming that all instrumentation is uniformly distributed within the lab module and on the pallet. Immediately behind the orbiter cabin there is a docking module (DM), and this is followed by a transfer tunnel to a small pressurized module. The pallet shown here is almost the size of the original one depicted in Figure 3.4, and for a seven-day mission 12,000-13,000 pounds of scientific instruments and subsystems can be mounted on the pallet and within the pressurized module (this weight allocation is for scientific instrumentation, basic subsystems for life support, power, thermal control, and some data handling and communication are furnished with the baseline support module and pallet).

The bottom part of Figure 3.9 shows a very preliminary layout for a possible combined Atmospheric, Space and Plasma Physics Facility, consistent with

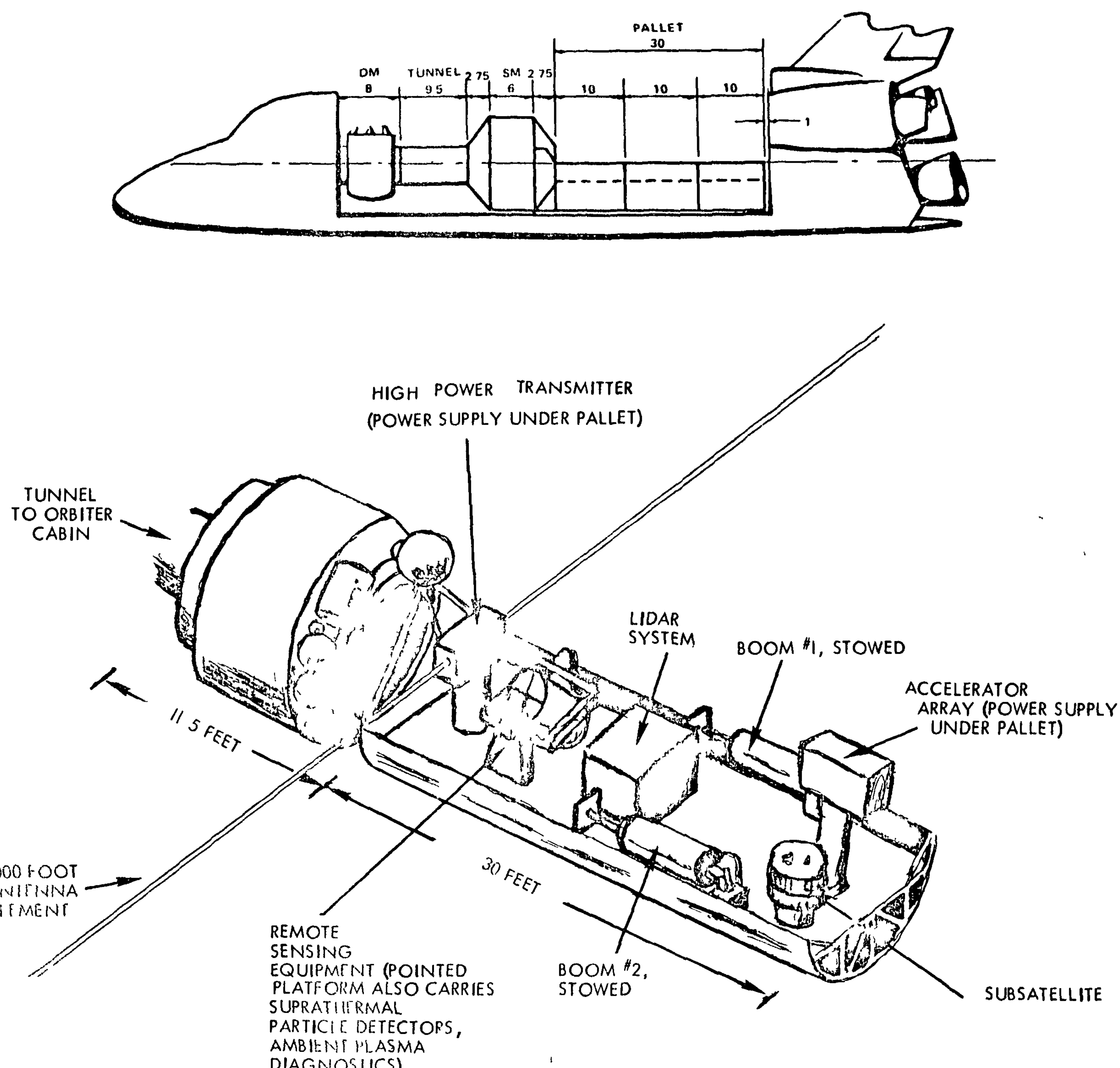

PALLET
30
DM
8
TUNNEL
9 5
2 75
SM
6
2 75
10
10
10
1
HIGH POWER TRANSMITTER
(POWER SUPPLY UNDER PALLET)
TUNNEL
TO ORBITER
CABIN
LIDAR
SYSTEM
BOOM #1, STOWED
ACCELERATOR
ARRAY (POWER SUPPLY
UNDER PALLET)
11 5 FEET
30 FEET
1000 FOOT
ANTENNA
ELEMENT
REMOTE
SENSING
EQUIPMENT (POINTED
PLATFORM ALSO CARRIES
SUPRATHERMAL
PARTICLE DETECTORS,
AMBIENT PLASMA
DIAGNOSTICS)
BOOM #2,
STOWED
SUBSATELLITE

Figure 3.9

the dimensions given at the top of the figure. In order to accommodate the Lidar system and the more elaborate remote sensing unit, power supplies are mounted below the pallet surface. A subsatellite similar to the Atmospheric Explorer is shown beside the accelerator, and the undesigned Lidar system is simply represented as a large package with no specific features. The remote sensing system shown here is based on the preliminary design of the Main Instrument Cluster and Gimbal unit studied by Martin Marietta in their analysis of an Atmospheric Science Facility (see Figure 3.10). This unit is approximately 10 feet across, 8 feet wide, and 8 feet high. The additional support requirements for the atmospheric instrumentation is summarized in Table 3.8.

Table 3.8

Optical Instrumentation

PPEPL Planned

- Gimbaled Platform
- TV System
- Photometer Bank
- Camera

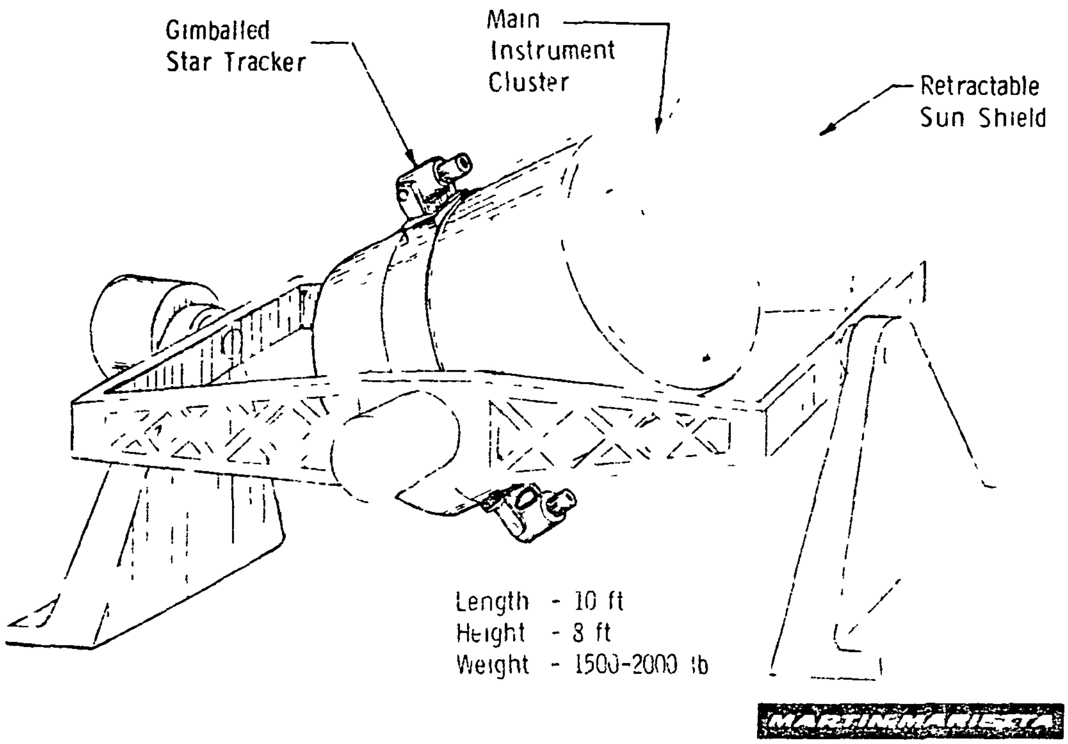
Additional for Atmospheric Observations

- Lidar (phased array)
- XUV Normal Incidence Spectrometer
- UV-VIS-NIR Normal Incidence Spectrometer
- Hi-resolution Fourier SWIR Spectrometer
- Cryo IR Fourier Spectrometer
- IR Radiometer
- Fabry-Perot Interferometer

Weight	580 kg + Mount	Pointing	$\pm 0.02°$
Power:	345 W	Data	2×10^6 + ? bps

If the pallet is not to be deployed out of the payload bay, there must be some way to move the high voltage units (transmitter and accelerator array) away from the shuttle itself. A very preliminary and simple scheme is indicated in Figure 3.9. The high voltage units are mounted on pedestals that can be extended to obtain adequate clearance.

MAIN INSTRUMENT CLUSTER AND GIMBAL



1) Horizon scanning of selected airglow features by high spectral resolution photometers and interferometers (primarily optical and IR range)

2) Vertical passive probing by infrared interferometry to determine the vertical distribution of constituents such as CO_2 and O_3 (1-5 mm, 5-150 mm)

3) Lidar probing of the lower atmosphere with pulses in the UV 2200-3000 Å range (separare system)

4) Measurement of the absorption of light in selected spectral regions between the shuttle and a steerable subsatellite

Figure 3 10

The increased display and control requirements coupled to a smaller available pressurized module make mandatory the requirement for developing a method of increasing the interior space utilization efficiency. One such method is depicted in Figure 3.11 in which the control and display equipment is located radially around the module walls. Two chairs, mounted on separate longitudinal poles or columns would be individually controlled by the on board scientists. Such an arrangement would provide for more efficient utilization of the reduced volume available but integration and test procedures on the ground would be more difficult.

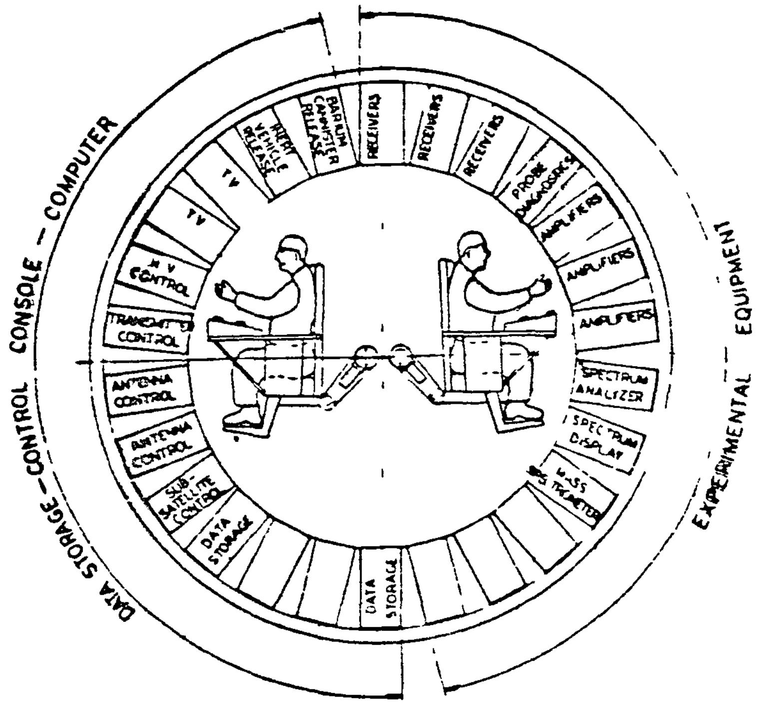


Figure 3.11. Cross Section of Pressurized Module Equipment Layout

It should be evident that no detailed technical analysis of the combined Atmospheric, Space and Plasma Physics Laboratory has yet been carried out; however, the initial evaluation does suggest that it will be feasible to design a combined facility that is entirely compatible with the new shuttle sortie mission restrictions.

Part 4

COST SCHEDULE AND SRT

4.0 COST SCHEDULE AND SRT

4.1 COSTING APPROACH

The cost data presented in the following sections are based on an assumed project plan calling for a series of 36 Plasma Physics Sortie Lab Missions in the period between 1980 and 1990. The plan is for the definition, design, development and fabrication of a Plasma Physics Laboratory facility, and the integration, delivery, launch support, launch, data acquisition, and data reduction programs that follow.

The design, development and fabrication of a plasma physics laboratory facility for the conduct of experiments in the area of space plasma physics environment perturbation is predicated on the availability of a sortie lab with its mounting platform, and the successful implementation of a space shuttle program that shall provide low cost transportation of the sortie lab to and from near earth orbit.

The Plasma Physics Environmental Perturbation Laboratory is to be a laboratory facility, rather than an experiment payload An experiment feasibility study performed in 1972 defined requirements for 36 sortie shuttle missions encompassing over 200 important space plasma physics experiments which received high priority in the study of space and magnetospheric physics. The PPEPL is to be designed as a general facility which will accommodate all the experiments in the area of plasma physics and environment perturbation The environment perturbation techniques envisioned for the PPEPL represent a new frontier for experimentation, study and analysis.

4.1.1 Ground Rules and Assumptions

Thirty-six plasma physics environmental perturbation missions have been defined during the experiment definition phase for the PPEPL.

A summary schedule showing the project milestones for the next 12 years is shown in Figure 4.1. The experiment planning teams are to be formed by NASA Headquarters Office of Space Sciences, the Physics and Astronomy Section. The APO for experiment planning teams is scheduled to appear at approximately the same time as the RFP for selection of a contractor to undertake the design definition phase of the PPEPL. The RFP shall be generated by MSFC with the approval of NASA Headquarters. Six experiment planning groups and the PPEPL design contractor shall be selected and contractually committed to the PPEPL project by December 1, 1973.

The Phase C-D contractor selected in Sept. 1975 shall fabricate the laboratory and upon completion of all subsystems deliver the laboratory to MSFC. Integrated system tests and experiment integration and coordination shall take place at MSFC. The selection of experimenters to man the first three missions shall be undertaken by NASA Headquarters with the support of MSFC. The first few groups to be selected shall be representatives from the more experienced space research investigators since they will be required to interact more fully with the Phase C-D contractor. Experimenters shall deliver all experiment unique equipment to MSFC for integration and the experiment mission profile shall be coordinated with Mission Control and the sortie shuttle mission plan. Training of the scientists and mission simulation activities shall be conducted at MSFC. Pre-flight support to the shuttle

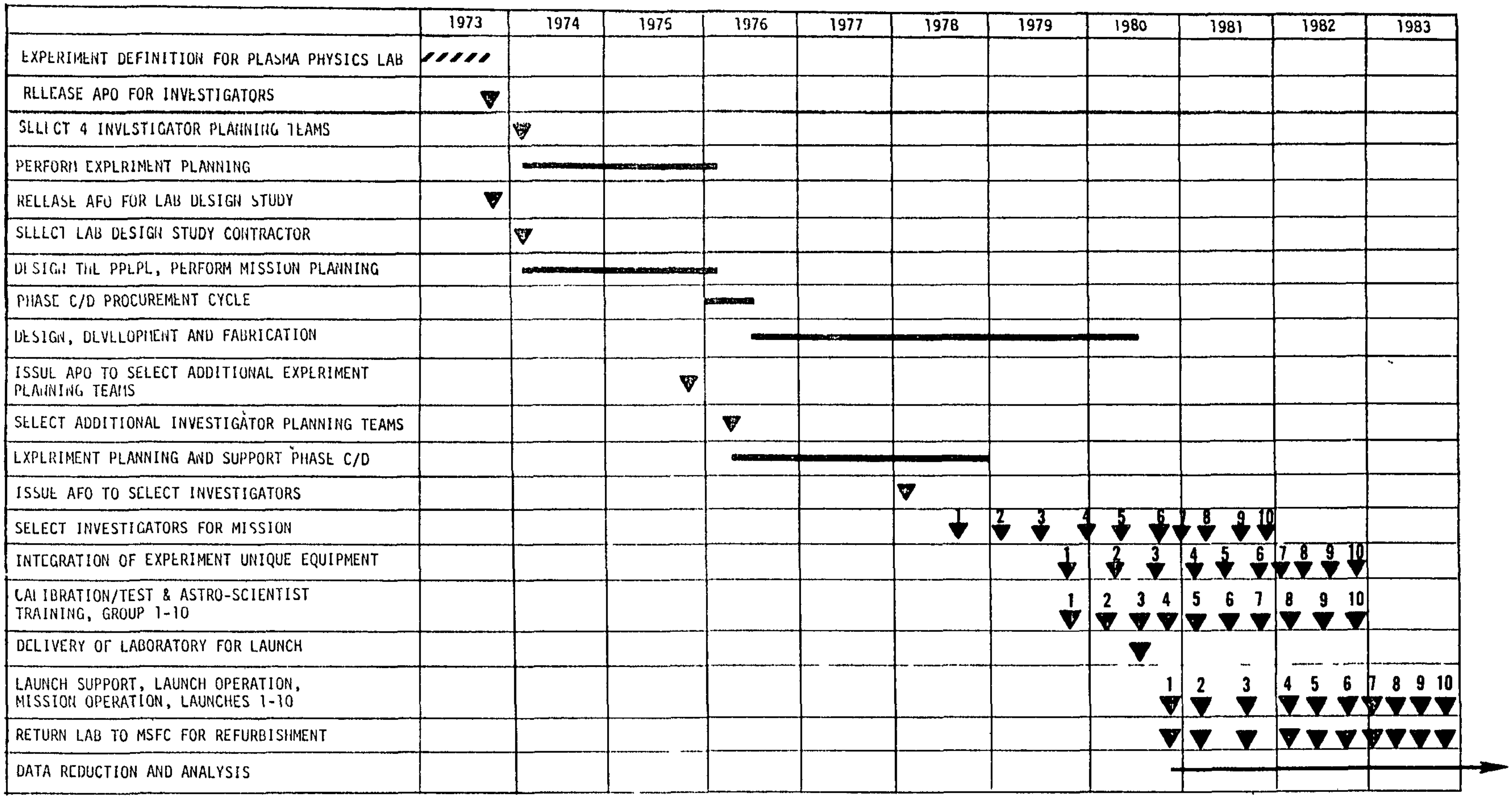

1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
EXPERIMENT DEFINITION FOR PLASMA PHYSICS LAB
RELEASE APO FOR INVESTIGATORS
SELECT 4 INVESTIGATOR PLANNING TEAMS
PERFORM EXPERIMENT PLANNING
RELEASE AFO FOR LAB DESIGN STUDY
SELECT LAB DESIGN STUDY CONTRACTOR
DESIGN THE PPLPL, PERFORM MISSION PLANNING
PHASE C/D PROCUREMENT CYCLE
DESIGN, DEVELOPMENT AND FABRICATION
ISSUE APO TO SELECT ADDITIONAL EXPERIMENT PLANNING TEAMS
SELECT ADDITIONAL INVESTIGATOR PLANNING TEAMS
EXPERIMENT PLANNING AND SUPPORT PHASE C/D
ISSUE AFO TO SELECT INVESTIGATORS
SELECT INVESTIGATORS FOR MISSION
INTEGRATION OF EXPERIMENT UNIQUE EQUIPMENT
CALIBRATION/TEST & ASTRO-SCIENTIST TRAINING, GROUP 1-10
DELIVERY OF LABORATORY FOR LAUNCH
LAUNCH SUPPORT, LAUNCH OPERATION, MISSION OPERATION, LAUNCHES 1-10
RETURN LAB TO MSFC FOR REFURBISHMENT
DATA REDUCTION AND ANALYSIS

Figure 4.1

mission control team shall be supplied by experimenters, the MSFC management team, and the spacecraft contractor during delivery of the PPEPL to KSC and during integration into the shuttle. A final mission simulation exercise shall be conducted at KSC prior to shuttle take off

During the flight, coordination between the experimenters in the PPEPL and experiment teams on the ground and the shuttle mission control teams shall take place at mission control. Mission control activities shall also encompass any other simultaneous experiments that may be required by the experimenter teams (e.g., simultaneous ground measurements or rocket launches) After landing and recovery of the data stored on the PPEPL, the first mission experiment team shall analyze and reduce its data while the second group of experimenters refurbish and test the PPEPL for the next flight.

The phase C-D design fabrication contractor shall fabricate two PPEPL sortie systems. The first laboratory shall be utilized for design verification, testing, and prototype environmental tests. This laboratory shall also be utilized for an engineering test model for astro-scientist training, for integration of experiment unique equipment, for calibration, test and checkout of equipment, and for small CVT studies. The second laboratory shall be the flight laboratory that is transported between KSC and MSFC

The project plan presented in the following sections is based on the development of a program that will allow for four PPEPL launches per year by 1982. The evolution of the program is to proceed slowly and methodically with one PPEPL launch in 1979, two in 1980, three in 1981, and four per year from 1982 onward

4.1.2 Project Plan and Operational Philosophy

1. General

The PPEPL project may be divided into three distinct phases The laboratory definition phase, the design, development and fabrication phase (C-D), and launch support, launch and data reduction phase (E)

2. The Laboratory Definition Phase

The laboratory definition phase shall be delegated to MSFC, the mission payload center. MSFC shall be supported by four to six experiment planning teams and a laboratory design and development contractor.

a. MSFC In-House Effort MSFC will supply the required manpower to provide liaison between the laboratory design contractor and experimenter groups, assure that the project proceeds in a technically sound direction, and remains on schedule, and that the tasks are accomplished within the available resources. An in depth experiment definition and laboratory definition effort is now being performed by MSFC with the support of contracted efforts and experiment working groups. This effort, which was completed in June 1973, yielded a complete definition of the PPEPL experiments, supporting equipment and the launch operational requirements for ground network support, mission control, and data processing.

During the PPEPL design fabrication phase, organizational elements of MSFC will be assigned to perform specific tasks similar to the ones being performed during the early phases of the program. Additional tasks performed by MSFC include

- Continue experiment analysis.
- Planning experiment development, including costs and SRT.
- Survey of instrument/sensor/equipment.
- Implement SRT identified in basic studies.

b. Experimenter Groups. The experimenter groups will be selected by NASA Headquarters through an Announcement for a Planning Opportunity (APO). Results of the experiment definition studies indicate that six to eight teams are required in order to proceed with the development of the PPEPL. The science teams will organize under the direction of a team leader and will conduct investigations that support the development of the PPEPL. The teams will develop a management plan including the assignments of responsibilities for each member which will be filed with the project scientist and updated at least once a year. The responsibilities of the science teams are

1. Participate in the definition of the instrument functional requirements.
2. Develop the calibration requirements pertaining to the investigation.
3. Assist in the evaluation of candidate hardware subcontractors
4. Assess the scientific implications of the instrument development and perform supporting investigations
5. Participate in the definition of the instrument test plans and data handling plans and review the test results.

6. Contribute to the spacecraft and mission design.
7. Participate in mission operations.
8. Develop or concur in the data analysis computer programs.
9. Report preliminary science results and provide preliminary and summary reports.

The objectives of each working group are to identify a set of scientifically valuable PPEPL experiments and define the data requirements and data acquisition procedures in sufficient detail to permit a conceptual design of PPEPL. Additional tasks performed by the working groups are

- Review the scientific objectives of each broad category, identify those objectives that yield the greatest scientific return from a PPEPL system.
- Investigate the feasibility and desirability of performing selected experiments from the PPEPL. Identify those experiments that best fulfill the scientific objectives.
- Study and define the constraints imposed by physical processes on the experiment, spacecraft and mission
- For a given mission profile, generate a chronological data acquisition plan.
- Evaluate and assess the impact on experiments resulting from classification of various equipment as "core" support and experiment peculiar.
- Identify the problem areas associated with the performance of experiments and generate tentative solutions
- Review and discuss problems of future interest to the advanced PPEPL programs

c. Contracted Effort: Overall Responsibility. The contractor shall be responsible to MSFC for the conceptual design and development of a PPEPL which can accommodate the broad range of experiments identified during the experiment definition study. The contractor shall also undertake mission planning, launch vehicle suppprt, GSE identification, test procedures, launch operation support, project plans, and hardware integration support. The contractor shall maintain liaison with the experiment working groups, the experimenter and NASA COR to ensure that the experiment design requirements are relevant and proper and are set forth in sufficient detail to be meaningful in the laboratory equipment layout. Additional tasks include

- Laboratory/Facility Configuration

  -Experiment peculiar bulkheads, racks, shelves.

  -Window placement, number, type and their effect on lab thermal/radiator analysis.

  -Access for inspection and repair.

  -Layout of experiment peculiar and common core equipment.

  -Total arrangement for best working conditions.

- Laboratory/Facility Subsystems

  -Electrical power conditioning and distribution

  -Dependent versus independent ECLS

  -Need and arrangement for crew habitability systems.

  -Analysis of pointing requirements, body pointing or gimbal

4.1.3 Work Breakdown Structure (WBS)

The overall WBS for the PPEPL project is shown in Figure 4.2. The details of the WBS down to level 5 are shown in Figures 4.3, 4.4, 4.5 and 4.6.

4.1.3.1. The Design and Definition Study and Experiment Working Groups. The design and definition study is a phase B program aimed at the preliminary design and development activities required to carefully define the system and the overall mission. The cost elements shown in Figures 4.2 and 4.3, at level 4, are limited in scope to detailed planning and identification of problems to be solved during the following phase The definition study will be supported by the experiment working groups described in the following sections.

4.1.3.2. Experiment Working Groups. The experiment working groups will be selected by NASA through the use of an Announcement of Planning Opportunity (APO). The cost elements associated with this WBS (Figure 4.4) are tasks that involve part time support (1 day per month) to a group of 6-12 scientists per working group, plus travel and per diem expenses

4.1.3.3 The Phase C. D Design and Fabrication. The PPEPL is manned and suitable for conducting research and applications activities on Shuttle sortie missions transported to and from orbit in the Shuttle payload bay and attached to to the Shuttle orbiter stage throughout its mission. The Sortie Lab will be characterized by versatile laboratory facilities, rapid user access, and minimum interference with the Shuttle orbiter turn-around activities. It also includes a pallet which is an unpressurized platform for mounting-booms-antenna and other instruments and equipment requiring direct space exposure for conducting research and applications activities on Shuttle sortie missions.

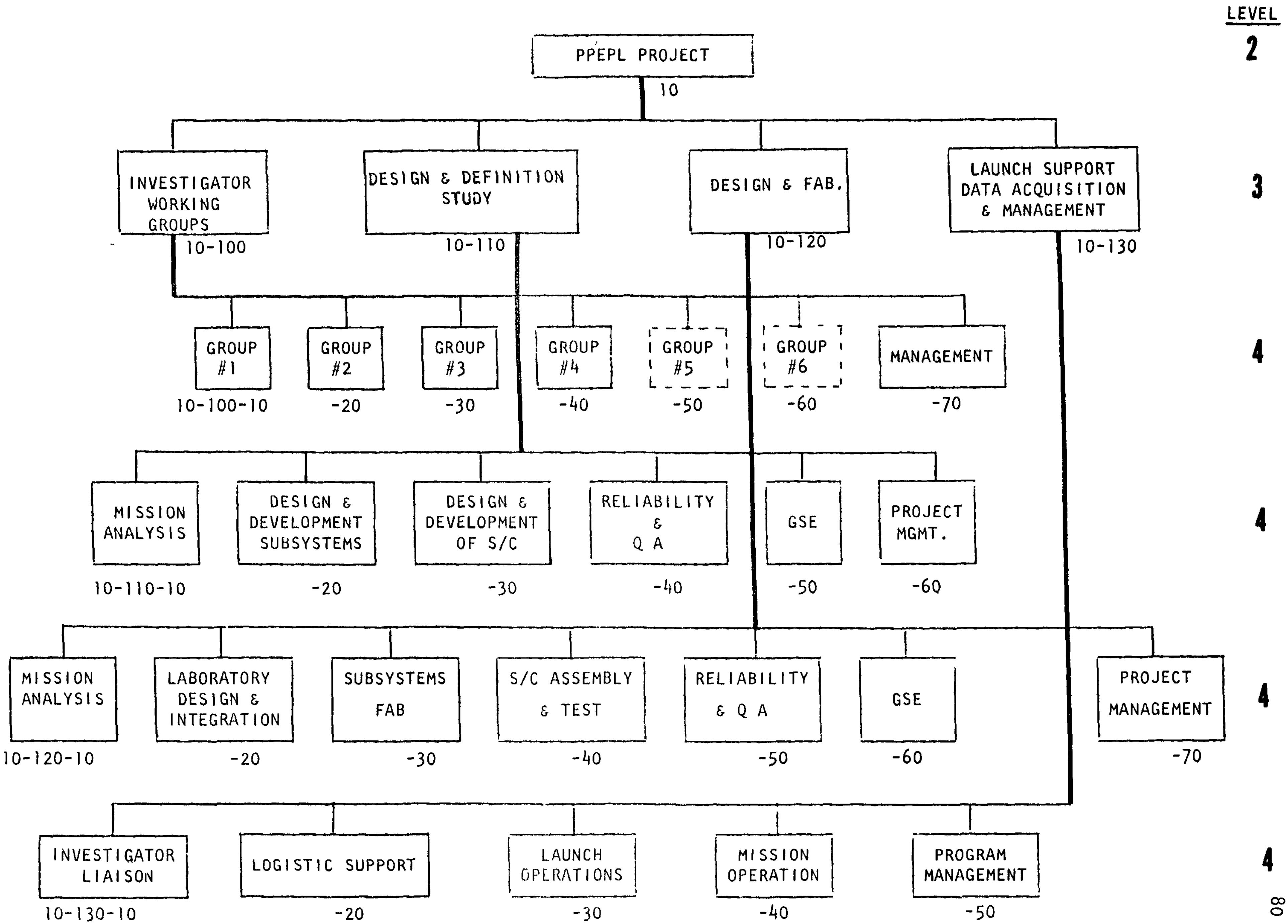

LEVEL
2
3
4
4
4
4
PPEPL PROJECT
10
INVESTIGATOR WORKING GROUPS
10-100
DESIGN & DEFINITION STUDY
10-110
DESIGN & FAB.
10-120
LAUNCH SUPPORT DATA ACQUISITION & MANAGEMENT
10-130
GROUP #1
10-100-10
GROUP #2
-20
GROUP #3
-30
GROUP #4
-40
GROUP #5
-50
GROUP #6
-60
MANAGEMENT
-70
MISSION ANALYSIS
10-110-10
DESIGN & DEVELOPMENT SUBSYSTEMS
-20
DESIGN & DEVELOPMENT OF S/C
-30
RELIABILITY & Q A
-40
GSE
-50
PROJECT MGMT.
-60
MISSION ANALYSIS
10-120-10
LABORATORY DESIGN & INTEGRATION
-20
SUBSYSTEMS FAB
-30
S/C ASSEMBLY & TEST
-40
RELIABILITY & Q A
-50
GSE
-60
PROJECT MANAGEMENT
-70
INVESTIGATOR LIAISON
10-130-10
LOGISTIC SUPPORT
-20
LAUNCH OPERATIONS
-30
MISSION OPERATION
-40
PROGRAM MANAGEMENT
-50

Figure 4 2

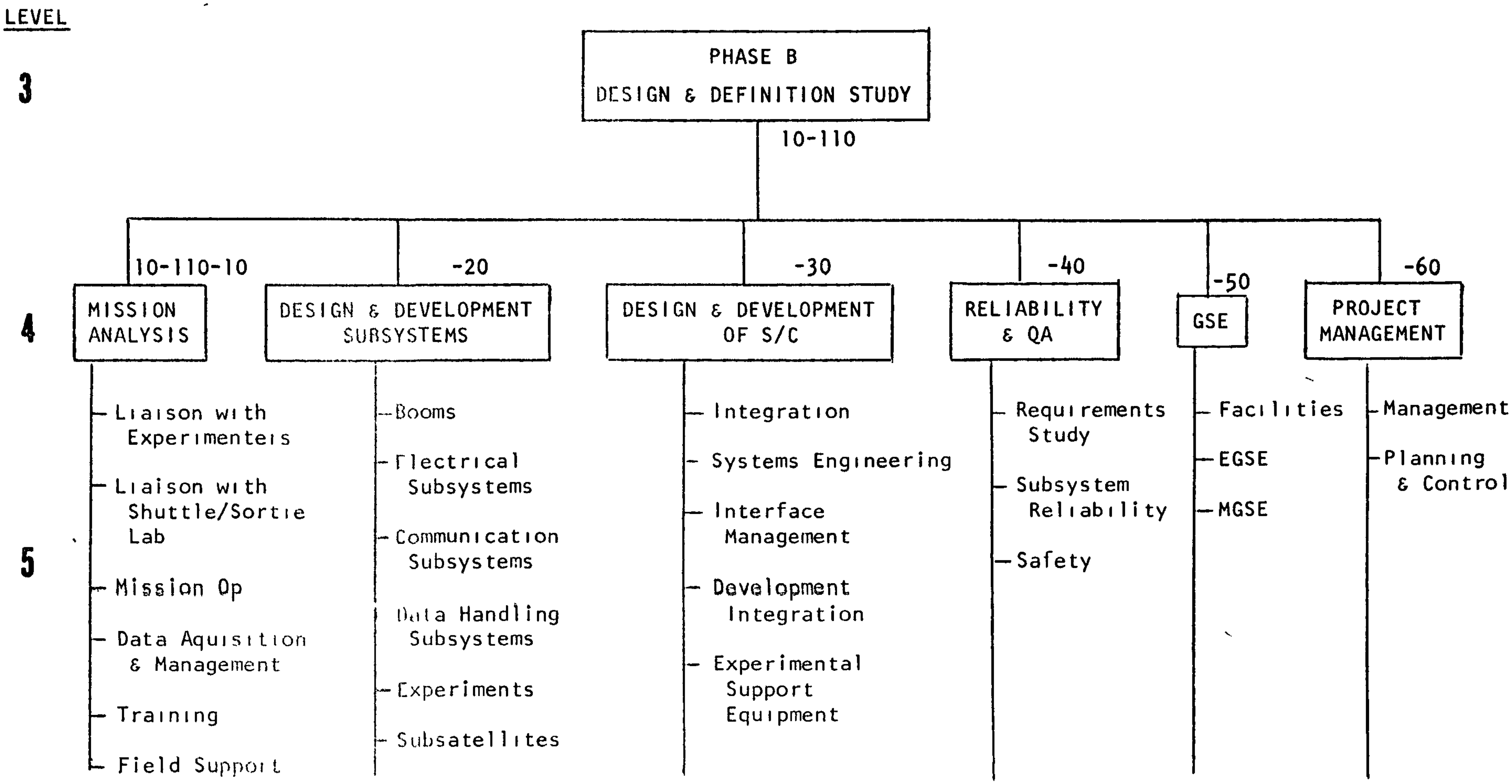

LEVEL
3
4
5
PHASE B
DESIGN & DEFINITION STUDY
10-110
10-110-10
MISSION ANALYSIS
Liaison with Experimenters
Liaison with Shuttle/Sortie Lab
Mission Op
Data Aquisition & Management
Training
Field Support
-20
DESIGN & DEVELOPMENT SUBSYSTEMS
Booms
Electrical Subsystems
Communication Subsystems
Data Handling Subsystems
Experiments
Subsatellites
-30
DESIGN & DEVELOPMENT OF S/C
Integration
Systems Engineering
Interface Management
Development Integration
Experimental Support Equipment
-40
RELIABILITY & QA
Requirements Study
Subsystem Reliability
Safety
-50
GSE
Facilities
EGSE
MGSE
-60
PROJECT MANAGEMENT
Management
Planning & Control

Figure 4.3

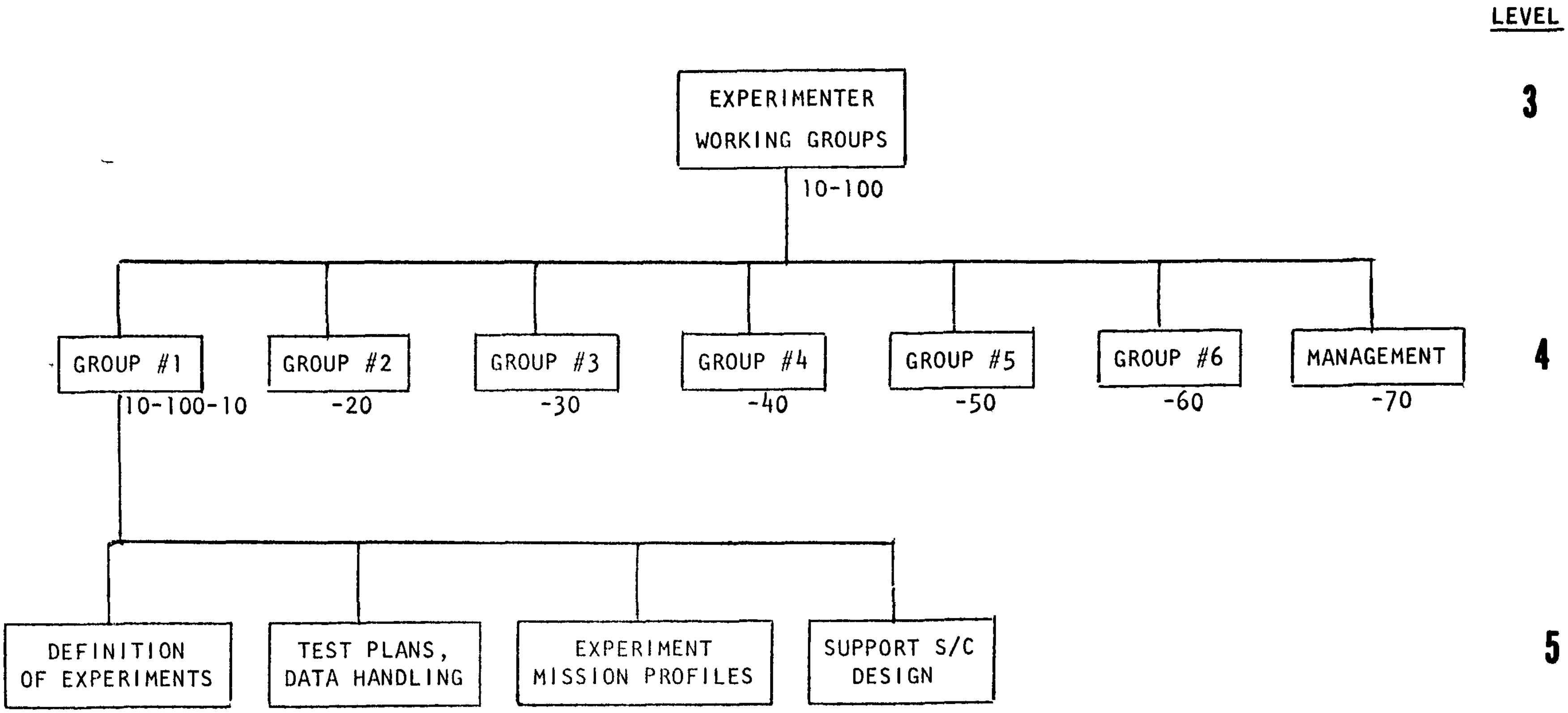

LEVEL
EXPERIMENTER WORKING GROUPS
10-100
3
GROUP #1
10-100-10
GROUP #2
-20
GROUP #3
-30
GROUP #4
-40
GROUP #5
-50
GROUP #6
-60
MANAGEMENT
-70
4
DEFINITION OF EXPERIMENTS
TEST PLANS, DATA HANDLING
EXPERIMENT MISSION PROFILES
SUPPORT S/C DESIGN
5

Figure 4.4

LEVEL

3

- PHASE C, D DESIGN AND FABRICATION — 10-120

4

- 10-120-10 MISSION ANALYSIS
- -20 LABORATORY DESIGN & INTEGRATION
- -30 SUBSYSTEM FABRICATION
- -40 S/C ASSEMBLY & TEST
- -50 RELIABILITY & QA
- -60 GSE
- -70 PROJECT MANAGEMENT

5

- MISSION ANALYSIS (10-120-10)
  - Plans & Requirements
  - Mission Op
  - Liaison with Experiment
  - Liaison with Shuttle Sortie Lab
  - Data Aquisition & Management
  - Training
  - Field Support
  - Mission Control Operations
- LABORATORY DESIGN & INTEGRATION (-20)
  - Experiments
  - Structure
  - Data Handling
  - Electrical Distribution
  - Mechanical
  - Electrical
  - Communication
- SUBSYSTEM FABRICATION (-30)
  - Requirements of Study
  - Experiments
  - Electrical Power
  - Structure
  - Communications
  - Data Handling
- S/C ASSEMBLY & TEST (-40)
  - Integration Requirements
  - Interface Requirements
  - Development Testing
  - Qualification Testing
  - Acceptance Testing
  - Test Hardware & Software
- RELIABILITY & QA (-50)
  - System Reliability
  - Subsystem Reliability
  - PMP Reliability
  - Vendor Surveillance
  - Verification Operations
  - Safety
- GSE (-60)
  - MGSE
  - EGSE
  - Fabrication
- PROJECT MANAGEMENT (-70)
  - Management
  - Configuration, Data Management & Administration
  - Planning & Control

Figure 4.5

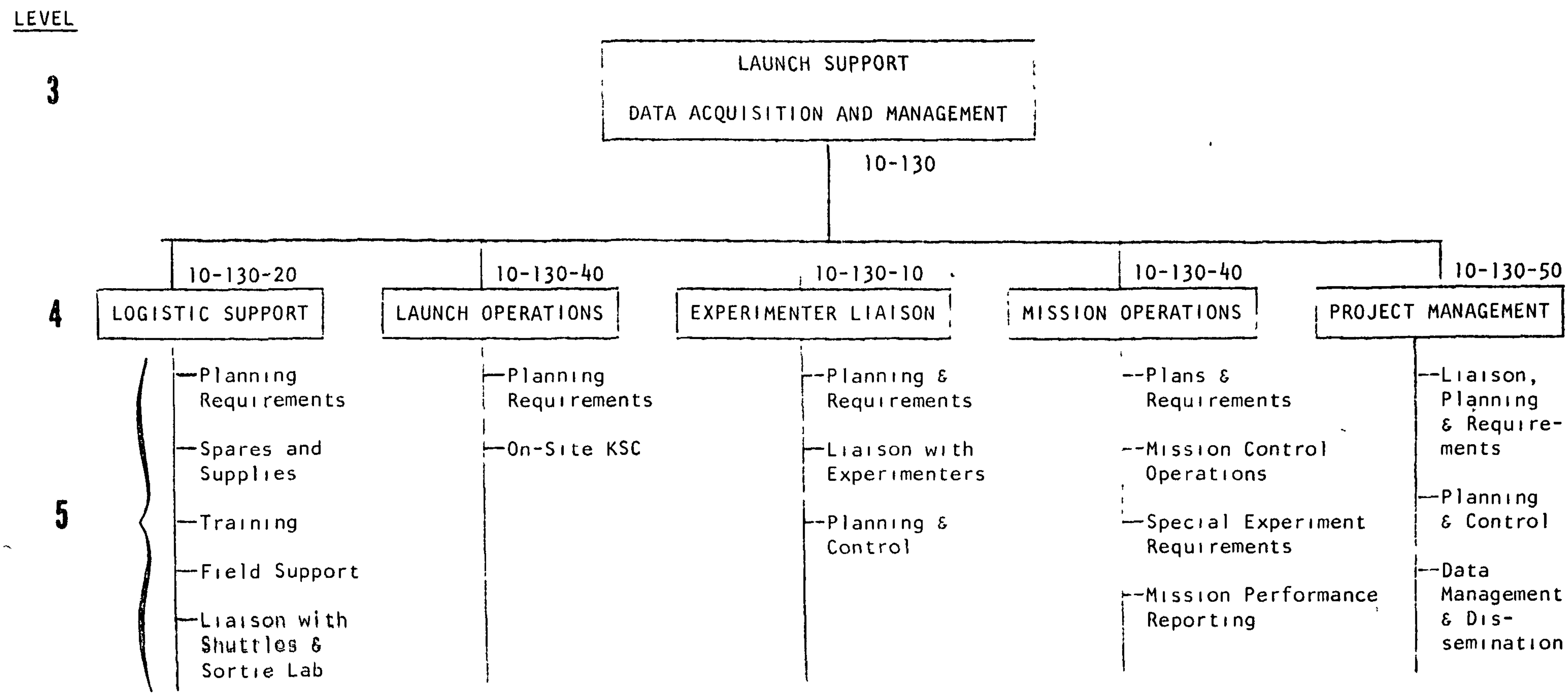

LEVEL
3
4
5
LAUNCH SUPPORT
DATA ACQUISITION AND MANAGEMENT
10-130
10-130-20
LOGISTIC SUPPORT
Planning Requirements
Spares and Supplies
Training
Field Support
Liaison with Shuttles & Sortie Lab
10-130-40
LAUNCH OPERATIONS
Planning Requirements
On-Site KSC
10-130-10
EXPERIMENTER LIAISON
Planning & Requirements
Liaison with Experimenters
Planning & Control
10-130-40
MISSION OPERATIONS
Plans & Requirements
Mission Control Operations
Special Experiment Requirements
Mission Performance Reporting
10-130-50
PROJECT MANAGEMENT
Liaison, Planning & Requirements
Planning & Control
Data Management & Dissemination

Figure 4 6

Figure 4.5 shows the WBS associated with phase C and D of the program.

Level 4 Project Management

This element sums the effort required to provide direction and control of the design and operation of the Early Lab experiment equipment. These efforts are required for planning, organizing, directing, coordinating, and controlling the project to insure that overall project objectives are accomplished. These efforts overlay the other functional categories and assure that they are properly integrated This element also includes the efforts required in the coordination and in gathering and disseminating information to the customer and associate contractor personnel

This element includes.

- Planning and control (technical and financial)
- Configuration management
- Production and procurement management
- Test operations management
- Quality assurance management
- Logistic support management
- Specification preparation and control
- Contract and documentation management
- Schedule control--master and supporting
- Conducting design reviews.

Level 4 System Engineering

This element includes all system engineering effort required to define and allocate engineering requirements necessary to direct and control an integrated approach to design, development, and operations, and all the effort required to plan and implement those activities necessary to insure a reliable, and maintainable product. It includes system analysis of performance and operational requirements, special studies and trade studies, system cost effectiveness evaluation, and interface requirements definition. Design reviews and technical performance measurement are also included in this element.

This element includes:

<u>Integration Engineering</u> (Cost data provided)

- Payload/Sortie Lab interfaces and compatibility rational
- Sortie Lab/Ground Operations interface
- Establish installation tolerances
- Mission-to-mission equipment changes
- Support test, checkout events
- Mass properties control
- Establish overall Interface Control Document
- Host vehicle evaluation

<u>Systems Engineering Functions</u>

- Requirements analysis, allocation
- System performance definition
- Cost effectiveness evaluation
- Interface control
- Experiment equipment layout in Sortie Lab
- Reliability plans
- Maintainability plans
- Safety
- Human factors
- Value engineering
- Support fabrication and assembly
- Quality Assurance plans.

Level 4 <u>Laboratory Subsystems</u>

This element sums all the engineering and production effort and hardware necessary to outfit the PPEPL with the subsystems and experiment related equipment and instruments. Included are: those items of hardware uniquely related to one experiment class of research, hardware common to two or more research classes, devices associated with the control/display function in the Sortie Lab, and the hardware needed to install the laboratory experiment equipment into the Sortie Lab host vehicle.

Common Core Equipment. The "common-core" designation identifies those items of equipment in a specified payload characterized by performance requirements which enable them to be shared by multiple experiments. Typically this group contains general purpose instrumentation (e.g., tape recorders, spectrum analyzers, general purpose computers, voltmeters, and frequency counters) which is procured from commercial vendors.

Control and Display Equipment. Those items of equipment required to perform control and monitoring functions in support of individual or collective experiments are consolidated into a "controls and displays" category. It includes power distribution, data recording, and computer capabilities.

Integration Hardware. The integration hardware is that flight-hardware/software which is necessary to assemble the experiment unique, common core and control and display equipment into an assembly that is capable of achieving experiment class objectives. This hardware includes birdcage structure racks, supports, cables, tie together devices, electrical harness, special end domes, antenna mounts, etc.

Level 4 System Test

This element includes all the effort, materials, hardware and services required to perform all system level test operations on experiment class equipment. The tests may be both independent of or in conjunction with PPEPL Sortie Lab and Shuttle testing.

This element includes:

System Test Hardware

- Dynamic/static structural and thermal models and assembly/component test articles
- Instrumentation and test fixtures

- Test articles and spares
- GSE used in system tests
- Simulation and environmental duplication devices
- Functional models (various scales).

Test Operations
- System test model plan
- Test conduct
- Test data reduction
- Test data evaluation and reporting

Experiment/Sortie Lab integration not included in this element.

Concept Verification Testing
- Mission simulation
- Equipment performance analysis
- Check on equipment layout/arrangement
- Human factors analysis.

Level 4 Ground Support Equipment

This element refers to all effort, material, and hardware needed to define, design, assemble, checkout, and deliver mechanical and electrical ground support equipment and also the mockups required for CVT, crew training, and mission monitoring during actual orbital operations Uses of the GSE and mockups are covered in other WBS elements. All GSE costs are considered only DDT&E (non-recurring) since the GSE produced under DDT&E would be the same equipment used in support of the experimental facility equipment.

This element includes·

Mechanical and Electrical GSE
- Hardware for handling, transport, and test support of experiment equipment
- Hardware for servicing, checkout and maintenance of experiment equipment
- Hardware to support launch and installation of any special experiment orientated equipment.

Mockups
- Full scale and scale mockups of experiment equipment/instrumentation for use in integration, CVT, and crew training work
- Full scale mockups of control and display panels for use in integration, CVT, and crew training work.

4.1.3.4 Launch Support, Data Acquisition and Management. This element includes all the effort and material and hardware needed to physically integrate the experiment equipment into the Sortie Lab, and after test and checkout events, pack and ship the integrated Sortie Lab to the launch site. It also includes all between missions refurbishment and maintenance functions that are planned as the overall concept for conduct of the project. The WBS for launch support, data acquisition and management is shown in Figure 4 6.

This element includes·

Experiment Integration
- Experiment interface requirements
- Experiment equipment reception, acceptance and storage
- Experiment interface hardware
- Experiment interface software
- Experiment interface testing
- Experiment installation in Sortie Lab and removal

Pack and Ship
- Packing/shipping containers
- Packing operations
- Transport operations

Refurbish Between Sortie Missions
- Remove and replace components and instrumentation
- Recalibration of instrumentation, scopes, and displays
- Maintenance and servicing normally accomplished at the launch/flight operations site as a result of discrepancies determined/disclosed through inspection, test, and verification activity. This may include fabrication type tasks such as strucutral repair, preservation and refinishing that are within the capabilities existing at the launch/flight operations site

Level 4 Logistic Support

This element sums all the effort, material, and equipment required for facilities to conduct the PPEPL program. Implicit here is the assumption that special ground facilities may be needed to properly conduct some of the PPEPL experiments and that new facilities or modifications to existing facilities may be needed

Level 4 Operations Support

All crew training actions, mission conduct efforts, and data processing/analysis events are included in this element. It covers the time period from acceptance through the lifetime of the laboratory and the time needed for data processing and analysis.

This element includes:

Crew Training

- Documentation and manuals on experiment equipment and controls/displays operation. Procedures. Orbital Operations handbook.
- Simulation drills in conjunction with CVT and mission planning events

Launch Operations

- Site activation
- Launch GSE installation and maintenance
- Join Sortie Lab to Shuttle, interface check with Shuttle
- Pad checkout of experiment equipment/instruments
- Countdown, launch, ascent monitor of equipment/instruments
- Post-launch deactivation

Orbital Operations

- Mission analysis and planning
- Update time lines
- Flight operations support to monitor experiment data and advise any changes to flight plan for experiment conduct
- Real time evaluation of priorities
- Real time quick-look check of experiment equipment functions
- Monitor experiment progress and status Resolve mission encountered anomalies and mission in-process replanning
- Coordination with data user agencies--real time data evaluation
- Logistic liaison with launch and mission control sites for "next flight" replenishment of expendable supplies and equipment

Data Processing

Decoding, normalization, rectification, indexing, and storage of on-board recorded and telemetry data.

Data Analysis

- Information extraction
- Comparative analysis
- Reports, documentation, maps.

Ground Stations for Tracking and Experiment Conduct

- Design, fabrication, and implacement of new facilities for mission control, data acquisition, command transmission, Shuttle Orbiter tracking, and data processing. Many Experiment Classes may require special ground transmission, reception, and tracking equipment placed at exact geographic locations to operate in synchronization with the PPEPL experiments.

Manufacturing and Test

- Construction of special manufacturing, assembly, integration and test facilities for the fabrication or qualification or integration of the Sortie Lab or experiment equipment.
- Modification of existing facilities to perform above activities.

4.1.4 Phase C-D Cost Analysis Assumptions and Guidelines

Listed below are the assumptions and/or guidelines that were followed in estimating the equipment and instrumentation costs for the PPEPL

1. The Environmental Perturbation Laboratory would be operational in 1979 and its flights in low earth orbit will be aboard the Shuttle orbiter. The first mission shall be followed by two missions in 1980, three in 1981, and four per year in 1982 and every year thereafter.

2. The host vehicle laboratory, Sortie Lab, which houses and supports the PPEPL facility is assumed to be GFE The Sortie Lab consists of a pressurized module with subsystems plus an attached tubular structured pallet as defined in the previous section

3. This study concentrates on the DDT&E (non-recurring) and the one-flight-production (recurring) costs of the hardware associated with production of two plasma physics facilities, an engineering test unit and a flight unit. It also makes provisions for operations and refurbishment costs.

4. Cost estimates are developed in conformance with the work breakdown structure and stated in fiscal year 1972 dollars

5. No learning curve has been assumed.

6. Costs assume commonality as a primary consideration, that the same prime contractor will have responsibility for designing and producing the PPEPL facility; that the same designs of one mission will be employed to the maximum extent possible for succeeding missions, and that the initial design employs maximum use of existing equipment

7. Costs are based upon TRW Systems historical cost estimating relationships.

8. The estimating methodology is generally applicable to low quantity and low production rate manned spacecraft, and cost improvement due to learning is not included for hardware at Level 5 or above.

9. All G&A and other overheads and burdens are included in each of the individual cost elements reported.

10. Costs are included for operations support, Sortie Lab integration, or specialized ground facilities or system tests, or mockups.

11. Project Management and System Engineering are based on one contractor developing the facility, related Common Core, and Controls and Displays.

4.1.5 Cost Estimating Relations and Cost Factors

The cost estimate is based on a comparative analysis between costs incurred on past programs and the task requirements for the PPEPL project.

Figure 4.7 shows the cost data generated for the Pioneer Program and the HEAO Program, with an estimated comparative cost for the PPEPL Laboratory. A fraction of the total program devoted to each of the elements of the Level 4 WBS is given in the first column for the Pioneer Program. The second column shows the same function for the HEAO Program. The third column is the estimated fraction that would be devoted to the PPEPL Project Note that in general the estimated fractional PPEPL costs are approximately the average costs incurred on Pioneer and HEAO. The deviations are in the area of Launch Support, Reliability, and QA. The assumption that QA costs would be lower than on past programs is based on the requirement that low cost equipment, possibly commercial equipment, be integrated into the laboratory. The sacrifice in reliability would be compensated by a reduction in cost and the availability of redundant equipment for performing either alternative experiments or the identical experiment with a reduction in scope. Since the number of possible experiments that could be performed is higher than the number flown on Pioneer and HEAO, it was estimated that the fraction of the program devoted to mission analysis and launch support would be higher

The cost of the Subsystems of the PPEPL Laboratory were determined by comparative analysis Figure 4 8 and Figure 4 9 illustrate the data used to generate the cost of one of the Level 4 subtasks, namely WBS 10-12030, shown in Figure 4 2 and Figure 4 5. Thus the cost for the Design and Fabrication of Subsystems for the basic PPEPL Laboratory were determined from the data presented in Figure 4 8, with the assumptions given in Figure 4.9. That total cost is shown to be 18.5M, 1972 dollars. All the other elements of the WBS for Level 4 are determined from the fractional estimate given in

COMPARATIVE COST STUDY

	Pioneer F,G %	HEAO A,B %	Estimate %	Standard PPEPL Cost	Austere Lab Costs	Complete Lab Costs
Management Administration	8	8 5	9	4.4	2.4	5.7
Mission Analysis Launch Support	1.2	11 7 4 3	14	6 8	3.8	8.8
S/C Design & Integration	18 6	21 4	20	9.7	5.4	12.5
S/C Design & Fabrication of Subsystem	43 1	32 7	38	18.5	10.3	23.8
S/C Assembly and Test	8 9	4.2	9	4.4	2 4	5.7
Reliability & QA	15 1	9 6	5	2.4	1.3	3.1
GSE	4 8	7.6	5	2.5	1.4	3 1
				48.7	27.0	62.7

Figure 4.7

C-2

EXAMPLE OF PPEPL SUBSYSTEMS—COST ANALYSIS

	Commercial Equipment Cat Cost	SIMILAR SPACE HARDWARE			ESTIMATED PPEPL COST				NOTES
			Cost/Unit		Cost/Unit		TOTAL	Two	
		Program and Assembly	DDT&E	Fab	DDT&E	Fab.	COST	Labs	
Time Code Generator	$7150	CNRL Timer/ Precision Clock	77.3	15.0			15.0	30.0	(1)
Boom Control #1		CNRL Drive Servo Electronics	302 0	50 0			352 0	402.0	(2)
Boom Control #2		CNRL 1/2 Drive Servo Electronics		50.0			50 0	100 0	(2)
Digital Tape Recorder #1	21,200	CNRL Digital Tape Recorder	150 0	150 0			42 4	84.8	(1)
Digital Tape Recorder #2	21,200			150 0			42.4	84 8	(1)
Frequency Synthesizer (HP 3320B)	14,000	CNRL Freq Synthesizer & Driver	134 7	27.3			28.0	56 0	(1)
Fluxgate Magnetometer		P-11 A F.	100 0	10 0	50 0	10 0	80 0	110 0	(3) (4)
Rubidium Magnetometer		OGO	450.0	50.0	225.0	50.0	375.0	525.0	(3) (4)
TRW Tetrahedral Research Satellite			1200 0	500.0			2200.0	3200.0	
TRW P&F Satellite			3500.0	1000 0			4600.0	7500 0	

1. Commercial equipment requires minor modification for use on PPEPL (assume PPEPL cost = 2 x (catalogue cost)
2. Commercial equipment not available, use space hardware costs
3. More than 50% of the system is incorporated into PPEPL as commercial equipment use 1/2 DDT&E costs and total fabrication costs.
4. Fab. 3 units per lab Boom mount, body mount, and gimbaled platform or spare

Figure 4.8

PPEPL COST ANALYSIS

ASSUMPTIONS

IN DETERMINING THE COST OF PPEPL SUBSYSTEMS

- IF THE SUBSYSTEM IS COMMERCIALLY AVAILABLE AND REQUIRES MINOR MODIFICATION

  PPEPL COST = 2 x (Catalogue Cost)

- IF COMMERCIAL EQUIPMENT IS NOT AVAILABLE

  PPEPL COST = (Similar Space Hardware Cost)

- IF MORE THAN 50% OF A SUBSYSTEM IS INCORPORATED INTO PPEPL AS COMMERCIAL EQUIPMENT

  PPEPL COST = 1/2 DDT&E COST + TOTAL SPACE HARDWARE FAB COST/UNIT

Figure 4.9

Column 3 of Figure 4.7. Thus given that 38 percent of the total PPEPL (Phase C,D) costs 18.5M dollars, the total program costs are 18.5/.38 = 48.7M dollars. The cost of each of the elements of Level 4 of the WBS are also determined. For example, WBS 10-120-70 Management Administration is given as 9 percent (Column 3 of Figure 4.7). The total cost of WBS 10-120-70 is then 9 percent of 48 7M, or 4.4M dollars. The cost of the other Level 4 elements are also shown in Figure 4.7 for the basic PPEPL, the Austere PPEPL, and the Growth PPEPL.

4.2 TOTAL PROGRAMMING FUNDING SUMMARY

The total program Cost Summary is presented in Figure 4.10. This is based on the assumptions shown in Figure 4.11. The total cost of the program for the period 1974-1982 is $148M. For the years 1983-1990, the annual cost for a 4-launch/year PPEPL experiment program is $52.3M Thus, the total cost of the program from FY 1974 to FY 1990 is approximately $514M, or approximately an average of 32M/year for a sixteen-year period

4.3 COST ESTIMATES BY WBS ELEMENTS

A cost breakdown is presented in Figure 4.12 based on the data presented in Section 4.1 5 and the WBS display, given in Figures 4.2, 4.3, 4.4, 4.5, and 4 6 The recurring production and operational costs and DDT&E costs are also identified and presented The total program cost at Level 2, WBS 10 for the period FY 1974 through 1982 is 148 05M dollars.

4.3.1 A Preliminary WBS Dictionary

The preliminary WBS Dictionary is presented in Figure 4.13

TOTAL PROGRAM COST SUMMARY
FY 1974 - 1982

	Subtotal (M)	Total (M)
Investigator Planning Teams		2.6
Design Definition	0.8	
Phase C,D	1.8	
Definition Study, Phase A,B		1.35
Phase A,B Study	0.65	
Management	0.7	
Phase C,D Design and Fabrication		47.9
Phase C,D Management		6.76
Launch Support		63 0
Data Acquisition and Management		26.44
Experiments	12.0	
SR&T Support	8 5	
Astro Scientist Training	3.0	
Management	2.94	
Total		148.05

Figure 4.10

ASSUMPTIONS

PPEPL COSTS TO PERFORM EXPERIMENTS GIVEN IN APPENDIX I

Assume 2 Sortie Labs delivered as GFE.

Assume Mission Model of 1 launch in FY 80, 2 launches in 1981, 3 in 1982 and 4/year in 1983-1990; total of 34 missions of 7 to 14 day duration/mission.

Experimenter Support - Assume 24 experimenters supported per year 1983-1990 with 200K/year for preparation and delivery of experiment unique equipment. For 24 experimenters per year, total cost is 4.8M/year.

Experiment-Refurbishment Support - Assume 500K per refurbishment for training, calibration, test, and administrative support. For 4 launches/year = 2M/year.

Launch Support - Assume 10.5 M per PPEPL launch.

SRT - Assume 2.5M/year SRT oriented towards PPEPL.

Figure 4.11

COST ESTIMATE BY WBS ELEMENTS

WBS Identification	Level	Recurring Production	Recurring Operation	DDT&E	No. Units	Total Cost
1.0	2					148.05
10-100	3			X		2.6
10-110	3			X		1.35
10-120	3			X		55.66
10-130	3			X		89.44
10-100-10	4			X		0.6
10-100-20	4			X		0.6
30	4			X		0.6
40	4			X		0.6
50	4			X		0.6
60	4			X		0.6
70	4			X		0.2
10-110-10	4			X		0.065
10-110-20	4			X		0.325
30	4			X		0.065
40	4			X		0.13
50	4			X		0.065
60	4			X		0.7
10-120-10	4			X		6.8
20	4			X		9.7
30	4	X			2	18 5
40	4	X			2	4 4
50	4			X		2 4
60	4	X			2	2 5
70	4			X		4.4
80	4			X		6.76
10-130-10	4		X			8.0
20	4		X			8.0
30	4		X			63.0
40	4		X			7.5
50			X			2.94

Figure 4.12

A Preliminary Work Breakdown Structure (WBS) Dictionary

Level	WBS ID No.	Description
2	10	PPEPL Project
3	10-100	Experiment Working Groups
3	10-110	Design and Definition Study
3	10-120	Design and Fabrication
4	10-100-10	Experiment Working Group #1
4	10-100-20	Experiment Working Group #2
4	10-100-30	Experiment Working Group #3
4	10-100-40	Experiment Working Group #4
4	10-100-50	Experiment Working Group #5
4	10-100-60	Experiment Working Group #6
4	10-100-70	Scientific Management
4	10-110-10	Mission Analysis
4	10-110-20	Design and Development of Subsystems
4	10-110-30	Design and Development of Spacecraft
4	10-110-40	Reliability and Quality Assurance
4	10-110-50	GSE
4	10-110-60	Project Management
4	10-120-10	Mission Analysis
4	10-120-20	Lab Design and Integration
4	10-120-30	Subsystems Fabrication
4	10-120-40	Spacecraft Assembly and Test
4	10-120-50	Reliability and Quality Assurance
4	10-120-60	GSE
4	10-120-70	Project Management
4	10-130-10	Experimenter Liaison
4	10-130-20	Logistic Support
4	10-130-30	Launch Operations
4	10-130-40	Mission Operations
4	10-130-50	Program Management

Figure 4.13

4.4 TECHNICAL CHARACTERISTICS DATA

The scientific payload capacity of the Shuttle Sortie Lab has been estimated at 20,000 to 35,000 lbs. It is clear that in the forthcoming era of space research the 1972 price per pound paid by NASA for experiments ($30,000-$100,000 per pound) is beyond the NASA budget capability if the payload capacity is fully utilized. One of the challenges of this study was to generate a new approach to reduce payload costs. Our approach is based on the use of commercially-available equipment as the basic building blocks of the PPEPL. The high weight, volume, and power capability of the space Shuttle makes redundancy as a means of increasing reliability more attractive. However, tradeoff studies relating to Safety, EMI, Thermal Control, Reliability, and Cost are required Standard practice reliability and QA standards must be generated, specifically for Shuttle Sortie payloads with the aim of reducing costs and maximizing payload functions.

The cost data presented in this report are based on the cost of commercial equipment given in 1972 dollars, and on comparative costs of similar space projects undertaken in the period 1970-1972. Not only is cost inflation not taken into consideration, but also predictions of the state of the technology 5-10 years hence have an extremely low confidence rating. It is therefore estimated that the total cost of the program may be increased or decreased by as much as 50 percent.

4.5 TOTAL PROGRAM FUNDING SCHEDULES

The annual costs for the total program are presented in the following charts. The assumptions underlying the data are given in Figure 4.11. Figure 4.1 is a detailed schedule based on the assumed package as a plan.

The total annual resource allocation is shown in Figure 4.14, with back up data given in Figure 4.15.

4.6 SYSTEM RESEARCH AND TECHNOLOGY REQUIREMENTS

Some significant technical problems will have to be studied in the next few years in order to develop a successful Plasma Physics and Environmental Perturbation Laboratory Facility. The important problem areas that need attention are the following. electromagnetic interference: general conducted and radiated interference control and potential problems associated with pulsing of high-powered transmitters and accelerators; outgassing and contamination; cooling of high voltage supplies, reflected light problems, particularly from deployed booms and antennas, accelerators. space charge forces, stable neutralization, purity of proton beam, cathode contamination by outgassing, electrostatic and magnetic "contamination" for the low energy gun; and baling in booms. Figure 4.16 presents an outline of these problems.

RESOURCE ALLOCATIONS BY FY------PPEPL

Expenditures in $1000 Units

FY:	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983-1990
CONTRACTED PROJECTS (Design, Development & Fab. of PPEPL)										
4 Investigator Planning Teams (100K/yr/Team)	400	400								
PPEPL Design Study & Mission Analysis	250	400								
Phase C-D Procurement		500	500							
Phase C-D Design, Dev., & Fabrication			4,100	13,300	16,100	9,900	3,500			
6 Investigator Planning Teams (100K/yr/Team)			600	600	600					
	650	1,300	5,200	13,900	16,700	9,900	3,500			
OTHER ACTIVITIES										
Selection of 6 Experimenters per mission, 4 Missions/yr possible by 1983	200K/yr/experimenter (Includes Data Reduction and Analysis) See Note #4, Chart D					6 Exp.	12 Exp.	18 Exp.	24 Exp.	
Astroscientist/Exp. Training Calib./Test of PPEPL Delivery, Return & Refurb. Data Reduction & Analysis	See Note #1, Chart D					Scientific Support Recurring Activities for Each Mission				
SRT—Design-Dev. & Fab. of Advanced Experiments & Advanced PPEPL	2.5M/yr. See Note #2, Chart D					6 Projects Identified				
Launch Support Mission Operation Data Acquisition & Dissem.	See Note #3, Chart D						Launch Support Logistics Recurring			
See Chart D for Details	280	280	1,440	1,700	1,700	4,400	16,600	29,200	41,300	366,100*
GRAND TOTAL	930	1,580	6,640	15,600	18,400	14,300	20,100	29,200	41,300	366,100*

*[illegible],300/yr for 7 years.

148 05

Figure 4 14

RECURRING COSTS-----PPEPL

Management (MSFC) Manpower (man-years)	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983 - 1990 (7 Years)
Phase B Studies (m-yrs)	* 7	7	3							Amounts are per year
Phase C, D Proposal	*		11							
Phase C, D Management	*		22	43	43	33	12	6		
Phase E	*					10	18	22	26	26
Man-Years, Management	7	7	36	43	43	43	30	28	26	26

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983 - 1990
40K/m-yr (Mgmt. Costs)	.280	.280	1.440	1.7	1.7	1.7	1.2	1.1	1.0	1.0
Astroscientist Training Calib., Test & Refurb. 500K/laboratory	Note #1						.5	1.0	1.5	2.0
Launch Support	Note #3 (10.5M/Vehicle)						10.5	21.0	31.5	42.0
SRF	Note #2					1.5	2.0	2.5	2.5	2.5
Experimenter Costs	Note #4					1.2	2.4	3.6	4.8	4.8
	.280	.280	1.440	1.7	1.7	4.4	16.6	29.2	41.3	52.3

*Based on WBS

Figure 4 15

SOME TECHNICAL PROBLEMS NEEDING ATTENTION

- EMI: GENERAL CONDUCTED AND RADIATED INTERFERENCE CONTROL. POTENTIAL PROBLEMS ASSOCIATED WITH PULSING OF HIGH-POWERED TRANSMITTERS AND ACCELERATORS.

- OUTGASSING AND CONTAMINATION.

- POWER PROFILE

- COOLING OF HIGH VOLTAGE POWER SUPPLIES

- REFLECTED LIGHT PROBLEMS

- ACCELERATORS: SPACE CHARGE FORCES, STABLE NEUTRALIZATION, PURITY OF PROTON BEAM.

  ELECTROSTATIC AND MAGNETIC "CONTAMINATION" FROM PPEPL/SHUTTLE (LOW ENERGY GUN)

  CATHODE CONTAMINATION BY OUTGASSING PROBLEMS.

- CABLING IN BOOMS, AND STOWAGE AND RETRACTION PROBLEMS

EXAMPLE, BOOM #1 ESTIMATE	Without Boom-Mounted Power Supply and Data Encoder (A/D Conv.,Multiplexer)	With Boom-Mounted Power Supply and Data Encoder
	Required Cables	Required Cables
	984 Ft, Shielded Twisted Pair	800 Ft, Shielded Twisted Pair
	19,520 Ft, #24 Wire	656 Ft, #24, #18 Wire
	1,968 Ft, Coax	480 Ft, Coax

Figure 4 16

Part 5

MISSION ANALYSIS

5.1 INTRODUCTION—OVERALL MISSION REQUIREMENTS

The eight experiment areas defined in Table 1.5 were analyzed in terms of individual experiment requirements to define subareas. The rationale for this subdivision was threefold:

- Common Experimental Objectives
- Common Instrument Requirements
- Common Mission Requirements

The experiment suggestions in an individual subgroup formed a single experiment in the mission plan. In developing the mission plan it was arbitrarily assumed that one attempt at a given experiment would consume one day. Each experiment was analyzed in terms of the number of times it would be performed to achieve a reasonable chance of success. For example, testing and calibrating a sensor would take two times at most while a high power VLF experiment could reasonably require five flights. Table 5.1 summarizes the subarea delineation and number of mission days required to complete the set of experiments suggested. Note that a total of 36 six-day sortie missions would be required for this program. With a build up in schedule to an average of 4 flights per year, a ten year experiment program could thus be mapped out.

Table 5.1

Delineation of Subareas and Mission Requirements

Area	Number of Subareas	Mission Days
(EP) Energetic Particles & Tracer	8	18
(BP) Beam Plasma Interactions	9	39
(WP) Wave Particle Interactions	10	41
(WC) Wave Characteristics	7	33
(WS) Wake & Sheath Studies	7	17
(MM) Magnetospheric Modification	6	15
(PD) Propulsion & Devices	7	13
(PP) Plasma Physics in Space	9	38
		214 Days or 36 Sortie Missions

In Table 5.2 we depict the requirements for simultaneous usage of the major subsystems in the PPEPL. From this table it is obvious that a breakdown into individual experiments, or the subareas of Table 5.1, is needed before instrumentation requirements can be defined for a given mission. In practice we believe time lines and mission instrumentation requirements can more properly be defined by the method described in Section 5 2.

5.2 DEVELOPMENT OF MISSION TIMELINES AND INSTRUMENTATION REQUIREMENTS

We see four steps as being required to develop mission timelines. First, the experimenter describes each sensor he will need for his experiment and how the experiment will be performed. Next, flow block diagrams for each sensor are generated. Figure 5.1 is an example of one such for a particle or photon detector. Other examples are given in Figures 2 2, 2.4, 2 5, 2.6, and 3 7 With a complete set of such block diagrams for each sensor and subsystem, a total list of display and control requirements can be made. A matrix with, say, columns representing the control and display consoles and rows representing the instrumentation and sensors is then constructed Such a matrix is shown in Figure 5.2. Using the block diagrams the display and control requirements for each instrument can then be charted on the matrix. (These are indicated by bullets in Figure 5.2.) Now the original experimenter required instrumentation will determine the complete complement of control and display equipment. Timelines, such as those depicted in Figure 5 3, are made for each instrument and the overall power and data profiles for the experiment are identified. These individual experiment timelines can then be combined for an overall mission timeline.

Table 5.2

Space Physics PPEPL Experiment Sub-Areas;

Simultaneous usage of the major subsystems.

	MAJOR INSTRUMENT & MISSION RQMTS.					
GEOPHYSICAL STUDIES OF THE DYNAMICS AND STRUCTURE OF THE MAGNETOSPHERE	Maneuverable Long Booms	Subsatellites	e^- and Ion Accelerators	Transmitting Antenna Receivers	Plasma Diagnostic Array	Other
WAVE CHARACTERISTICS (35 Experiment Concepts)	●	●	○	●	●	
WAVE-PARTICLE INTERACTIONS (18 Experiment Concepts)	●	●	●	●	●	
MAGNETOSPHERIC MODIFICATION (21 Experiment Concepts)	●	●	●	●	●	Correlated ground observations
BEAM-PLASMA INTERACTIONS (23 Experiment Concepts)	●	●	●	○	●	
ENERGETIC PARTICLES AND TRACERS (20 Experiment Concepts)	●	●	●	○	●	Ion injection and release capability
STUDIES IN THE FIELD OF PLASMA PHYSICS						
PLASMA PHYSICS IN SPACE (15 Experiment Concepts)	●	○	○	●	●	Large magnets
WAKE AND SHEATH (29 Experiment Concepts)	●	●			●	Deployment of large targets
PROPULSION AND DEVICES (22 Experiment Concepts)	●		●		●	

● Indicates that 75% of the experiment concepts in that area have a firm requirement for the subsystem.

○ Indicates that 75% of the experiment concepts would benefit from the subsystem, however, the subsystem is not a firm requirement.

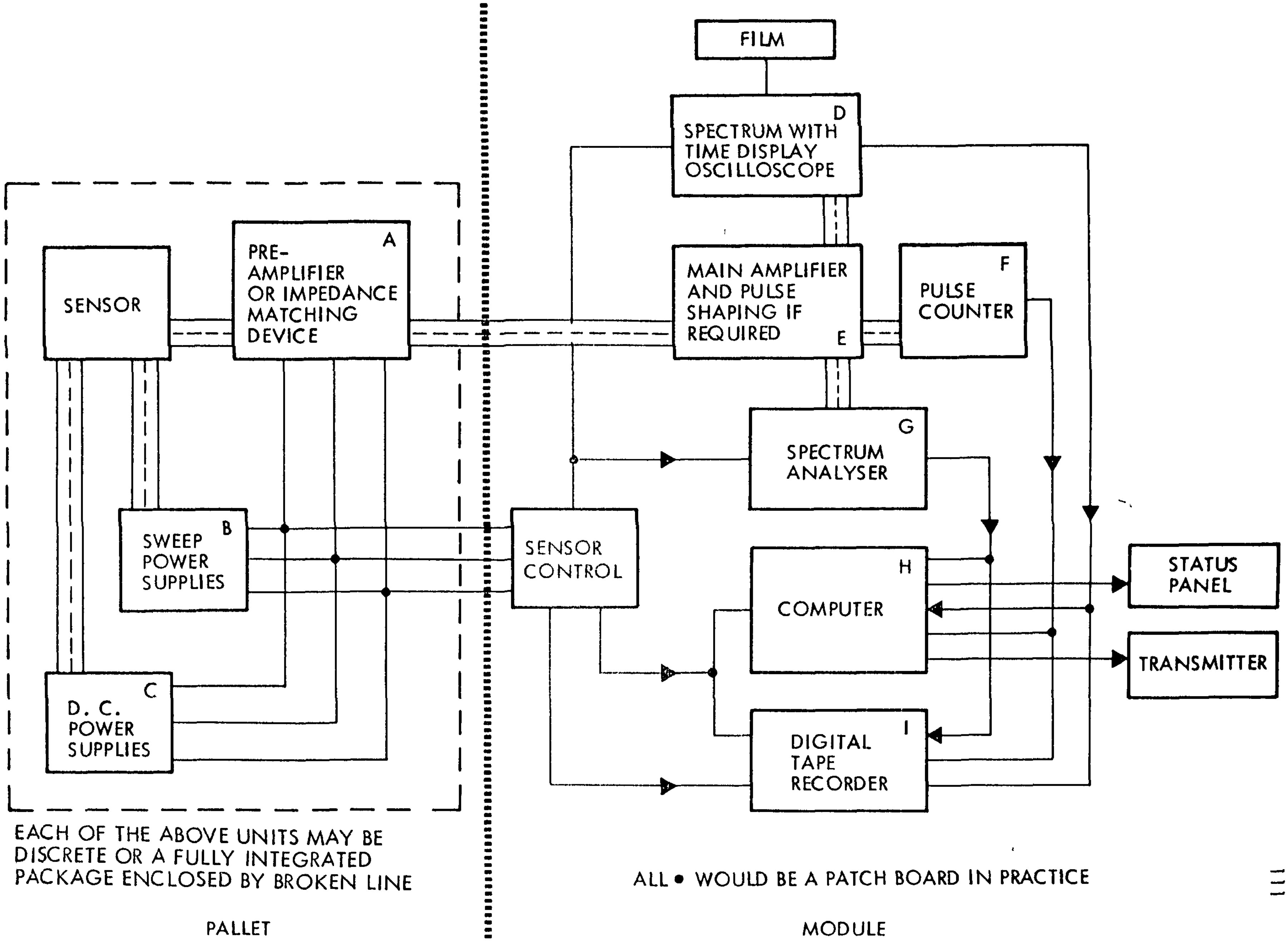


Figure 5.1 TYPICAL PARTICLE OR PHOTON ANALYSIS SYSTEM

CONTROL AND DISPLAY REQUIREMENTS FOR PPEPL INSTRUMENTATION

Instrumentation Description	
–	ACCESS CONTROL
A1	ION ACCELERATOR
A2	HV STORAGE TANKS
A3	ELECTRON ACCELERATOR
A4	MPD ARC
T1	0.2 to 2 MHz TRANSMITTER
T2	2 to 70 MHz TRANSMITTER
T3	0.3 to 200 kHz TRANSMITTER
T4	330 m DIPOLE
BA	50 m BOOM A
BA1	GIMBALED PLATFORM
BA2	5 m BOOM K
BA3	1 m LOOP
BA4	SHORT ELECTRIC DIPOLE
BA5	TRIAXIAL SEARCH COIL
BA6	5 m BOOM L
BA7	RUBIDIUM MAGNETOMETER
BA8	TRIAXIAL FLUXGATE
BA9	33 m DIPOLE
BA10	POWER SUPPLY
BA11	DATA SYSTEM
BA12	ALIGNMENT T V
BA13	ION MASS SPECTROMETER
BA14	SPHERICAL ION PROBE
BA15	CYLINDRICAL ION PROBE
BA16	PLANAR SEGMENTED PROBE
BA17	NEUTRAL MASS SPECTROMETER
BA18	TRIAX HEMI ANALYZER
BA19	PLANAR ELECTRON TRAP
BB	50 m BOOM B
BB1	WAVE GENERATOR
BB2	TARGET
G	GIMBALED PLATFORM
G1	ION MASS SPECTROMETER
G2	NEUTRAL MASS SPECTROMETER
G3	ELECTROSTATIC ANALYZER
G4	MAGNETIC ANALYZER
G5	PARTICLE DETECTOR
G6	TOTAL ENERGY DETECTOR
G7	T V SYSTEM
G8	PHOTOMETER BANK
G9	CYLINDRICAL PROBE
G10	SEGMENTED PLANAR PROBE
G11	RF PROBE
G12	PLANAR PROBE
G13	CAMERA
DBC1	100g Ba CANISTER
DBC2	1 kg Ba CANISTER
DBC3	10 kg Ba CANISTER
DSC1	1 kg Ba CHARGE
DSC2	5 kg Ba CHARGE
DSC3	20 kg Ba CHARGE
DG1	X (GAS RELEASE)
DG2	Y (GAS RELEASE)
DG3	Z (GAS RELEASE)
DB1	SPH INSUL BALLOON
DB2	SPH COND BALLOON
DS	DEPLOYABLE SATELLITE
DS1	T V SYSTEM
DS2	MAG 3 AXIS FLUXGATE
DS3	MAG SEARCH COIL
DS4	CYL ELEC PROBE
DS5	SEGMENTED PLANAR TRAP
DS6	ION MASS SPECTROMETER
DS7	TRIAX HEMI ANALYZER
DS8	VLF RECEIVER
DS9	E-FIELD METER

D1 through D32 Display Consoles

C1 through C136 Control Consoles

(Bullets indicate display and control requirements for each instrument)

EXPERIMENT OPERATIONS DATA

Title WC-XX PLASMA RESONANCES

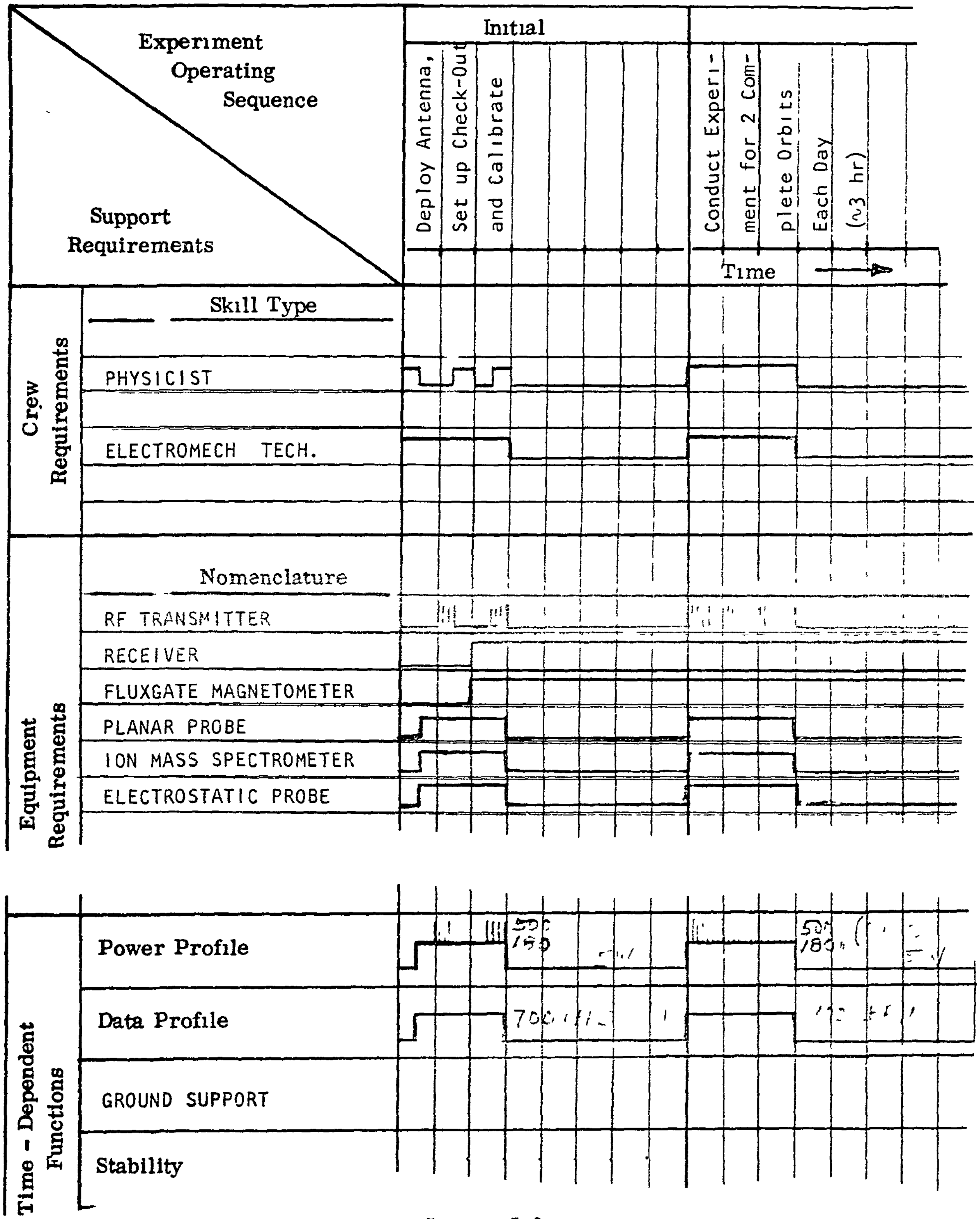


Figure 5.3

5.3 EXAMPLE OF REQUIREMENTS FOR A WAKE AND SHEATH EXPERIMENT

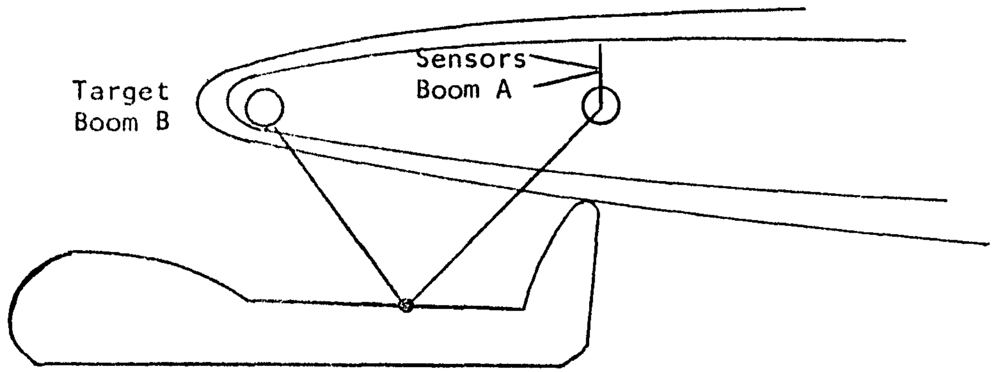
We have taken the example of one of the simpler PPEPL experiments to demonstrate the complexity of control and display requirements. In the top of Figure 5.4 we schematically depict a wake and sheath experiment. Two booms are required—the first to deploy a target, the second to measure the effects on the ambient environment of the target. The bottom of Figure 5.4 shows the display and control requirements.

In Table 5.3 we depict the types of data required and the problems associated with developing the proper data displays. These problems include both the one of being able to correlate and assimilate the wealth of information available and of using this information to control the experiment.

5.4 A SAMPLE MISSION

In order to demonstrate some of the problems and considerations that must be faced in developing a mission, we have chosen a concrete example for analysis. The rationale for choosing this mission and the four experiments chosen are given in Table 5.4. Background information, experiment objectives, and experiment methodology for the four experiments are given in Tables 5.5 through 5.8. Orbit and operations considerations for this mission are enumerated in Table 5.9.

EXPERIMENTAL PARAMETERS OF A TYPICAL WAKE & SHEATH EXPERIMENT



TWO BOOM DEPLOYMENT

TARGET BOOM (B)

CONTROL

Extension
Position
Target State (Inflation)

DISPLAY

Position of Balloon

(Shuttle centered, earth centered, geomagnetic)

DIAGNOSTIC BOOM (A)

CONTROL

Extension
Orientation of Platform
Position of Platform
Instrument Subsystems

DISPLAY

Position of Platform (shuttle centered, earth centered, geomagnetic)
Orientation of Platform (TV display to line up platform with respect to target)
Monitor Output of Multiple Instrument Subsystems

AUXILIARY DISPLAYS

Distance between Booms

Shuttle Velocity Vector V_s

Angular Position of Booms Relative to V_s

Direction of the Magnetic Field Relative to the Line Connecting Boom A to Boom B

Sample Ambient Continuously to Assure that Measurements are Wake Generated

Figure 5.4

Table 5.3

SAMPLE PROBLEMS AND TRADE STUDIES

DATA REQUIREMENTS

Position and Control of Booms and Boom A Platform

- Shuttle Centered Coordinate Frame
- Earth Centered Coordinate Frame
- Inertial Coordinates
- Boom B Centered Coordinate Frame
- Geomagnetic Coordinate Frame
- Magnetic Coordinates (harmonic expansion of surface field)
- Velocity Vector of Shuttle versus Shuttle Orientation

Auxiliary Data

Monitor the display from a maximum of 16 instrument subsystems, 19 ambient plasma monitors, and 4 special parameters (distance between booms, V_s, etc.)

PROBLEMS

- How does one best display the positions for a given task?
  - Boom Centered
  - Geographic Coordinates
  - Geomagnetic Coordinates
- What are the disadvantages/advantages of a geomagnetic coordinate display versus direct measurements of the field direction and magnitude?
  - Magnetic Cleanliness
  - Computer Programming
- How many separate, simultaneous coordinate displays are required to perform the experiment?
  - Reduction of multiple simultaneous displays to a single display (e.g., Boom B centered coordinates with the field direction displayed on the screen)
- How does one control the booms and simultaneously monitor other position parameters, target state, instrument readings (16 instruments), and the ambient environment (19 instruments)?

Table 5.4

Rationale for Sample Mission	Experimental Areas Chosen
1. AUSTERE LABORATORY CONSTRAINTS a. State of Development b. Simplicity of Operation	1. RF Heating/Sounder 2. VLF Boom-to-Boom Transmission
2. SCIENTIFIC CRITERIA a. Areas of Broad Interest b. Experiments with Several Modes	3. Simple Wake-Sheath Package 4. Beam-Plasma Experiment

Table 5.5

RF Heating/Sounder Experiment

BACKGROUND

1. Alouettes I, II
2. ISIS I, II
3. Rockets
4. Laboratory & Ground-Based Experiments

PRIMARY OBJECTIVE

Local Acceleration

SECONDARY OBJECTIVES

Resonances
Parametric Instabilities
Non-Linear Plasma Effects

METHOD USED

1000 ft Electric Dipole
High Power Wave Injection
$\sim$200 kHz to $\sim$2 MHz
Plasma Particle Spectrometers
Receiver Return Signals

Table 5.6

VLF Electrostatic Wave Transmission Experiment

BACKGROUND

Blue Book Area
Observed S/C Interference
Laboratory Experiments
(Crawford, Thomas, Pedersen)

PRIMARY OBJECTIVE

Transmit: Ion Sound Waves
Ion Cyclotron Harmonics

SECONDARY OBJECTIVES

Measure: Growth/Damping
Phase/Group Speeds

Study: Non-Linear Mode Coupling
Dispersion Relations

METHOD USED

Modulated grids or other electrode geometries to excite longitudinal sound or cyclotron harmonic waves

Short dipole antennas on second boom to receive signals.

Plasma diagnostics package for supporting background data on density, temperatur, magnetic field direction

Table 5.7

Wake-Sheath Experiment

BACKGROUND

Blue Book Area
Explorer 31 Observations
Gemini Observations
Moon Observations
16 Different Theories

PRIMARY OBJECTIVE

Study: Wake of Target Body
Sheath of Target Body

SECONDARY OBJECTIVES

Surface Physics of Target
Shape Factors

METHOD USED

Deployable Target Body on Boomlet
Plasma Diagnostics Package on Boom

Table 5 8

Beam-Plasma Experiment

BACKGROUND

Small low density beams have been flown and have not generated collective oscillations. Small auroral spots have been generated.

PRIMARY OBJECTIVE

Study collecting effects in plasma instabilities.

SECONDARY OBJECTIVE

Produce Artificial Aurora

METHOD USED

Electron or proton accelerator
Optical package on gimbaled platform.
VLF experiment diagnostics

Table 5.9

Mission Profile Impact

Choose 30° Inclination, Near-Equatorial Orbit

ADVANTAGES

1. Helps to reduce variability of B-direction.
2. Maintains most constant plasma conditions away from terminators.

DISADVANTAGES

1. Experiments primarily interested in polar cap and high-latitude field line regions cannot be accommodated.

PROBLEM AREAS IN OPERATIONS

1. Day-night ionospheric properties.
2. Time sharing and timelines.
3. Ground data support.
4. Pointing accuracies relative to B-direction.
5. Boom vibrations and displacements.

Appendix 1

INDEX

BEAM-PLASMA INTERACTIONS

Experiment Number	BP Subgroup Code	Experimenter(s)	Affiliation
BP-1	B	Nishida, Tohmatsu	University of Tokyo, Japan
BP-2	F	Roederer	University of Denver
BP-3	A	Armstrong	Johns Hopkins University
BP-4	B	Armstrong	Johns Hopkins University
BP-5	B	Potemra	Johns Hopkins University
BP-6	C	Sharp	Lockheed, Palo Alto
BP-7	A	Winningham	Univ of Texas at Dallas
BP-8	C	Maier, Chandra	NASA/GSFC
BP-9	D	Hoch, Stokes, Parks, Liemohn, Clark, et al	Battelle Northwest Lab's University of Washington
BP-10	B	Anderson, Cloutier, Michel	Rice University
BP-11	A	Pellat	Ecole Polytechnique, Paris, France
BP-12	B	Davis, Westcott	Geophysical Inst , Univ of Alaska
BP-13	A	Russell	Inst of Geophysics, UCLA
BP-14	A,B	Trichel	NASA/JSC
BP-15	A	Bernstein	NOAA, Boulder
BP-16	B	Hess	NOAA, Boulder
BP-17	A	Grewal, Smith	Wichita State University
BP-18	A	Thompson	Univ of California, San Diego
BP-19	A	Linson	Science Applications, Inc
BP-20	A	Walt	Lockheed, Palo Alto
BP-21	C	Zmuda	Johns Hopkins University
BP-23	A	Bertotti, Formisano	Instituto di Fisica "G. Marconi," Italy
BP-24	D	Anderson, Lin Chase	Univ of California, Berkeley

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MAGNETOSPHERIC MODIFICATION

Experiment Number	MM Subgroup Code	Experimenter(s)	Affiliation
MM-1	C	Cohen	NOAA, Boulder
MM-2	A,B	Brice	Cornell University
MM-3	B	Giorgi, Gregori	Instituto di Fisica dell' Atmosfera, Italy
MM-4	A	Paulikas	Aerospace Corporation
MM-5	C,D	Linson	SAI, San Diego
MM-6	A	Bernstein, Evans Williams	NOAA, Boulder
MM-7	A	Mozer	Univ of California, Berkeley
MM-8	A	Cole	La Trobe Univ, Australia
MM-9	D	Freeman	Univ of St Thomas, Houston
MM-10	A	Bullough	The University, Sheffield, England
MM-11	C	Chang, Hasegawa Lanzerotti	Bell Laboratories
MM-12	B	Helliwell, Bell	Stanford University
MM-13	A	Davis, Wescott	University of Alaska
MM-14	C	Crawford	Stanford University
MM-15	A	Hess	NOAA, Boulder
MM-16	B	Perkins	Princeton University
MM-17	A	Cahill	University of Minnesota
MM-18	A	McCormac	Lockheed, Palo Alto
MM-19	A,C	Linson	SAI, San Diego
MM-20	C	Linson	SAI, San Diego
MM-21	B	Giorgi, Gregori	Instituto di Fisica Dell' Atmosfera, Italy

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WAKE AND SHEATH STUDIES

Experiment Number	WS Subgroup Code	Experimenter(s)	Affiliation
WS-1	A	Oya, Ejiri, Aso	Univ of Tokyo & Kyoto, Japan
WS-2	A,C	Samir	Univ of Michigan, Tel-Aviv
WS-3	F	Phillips	Pennsylvania State Univ
WS-4	F	Winningham	Univ of Texas at Dallas
WS-5	F	Matthews	Univ of Maryland
WS-6	A,B,C	Taillet, Fournier	ONERA, Chatillon, France
WS-7	A	Whipple	NOAA, Boulder
WS-8	E	Freeman	Inst of Storm Research, Houston
WS-9	A	Troy, Maier	NASA/GSFC
WS-10	A	Brace	NASA/GSFC
WS-11	A,C	Raitt	Univ College, London, England
WS-12	B	Hanson, Hoffman	Univ of Texas at Dallas
WS-13	C,D	Prakash, Bhavsar	PRL, Navrangpura, India
WS-14	C,D	Muldrew	Comm Res Centre, Ottawa, Canada
WS-15	A	Rees	University of Colorado
WS-16	B,F	Vasyliunas	MIT
WS-17	E	Olson	McDAC, Huntington Beach
WS-18	B	Thompson	Univ of California at San Diego
WS-19	D	Smith, Grewal	Wichita State University
WS-20	F	Manka	Rice University
WS-21	F	Bowhill	Univ of Illinois
WS-22	D	Taylor Morgan	NASA/GSFC Dartmouth College
WS-23	D	Mozer, Bering	Univ of Calif at Berkeley
WS-24	A	Goedeke	McDAC, Huntington Beach
WS-25	F	Pedersen	ESTEC, Noordwijk, Netherlands
WS-26	F	Calabria	CSC, Silver Spring
WS-27	C	Hoch, Parks, et al.	University of Washington Battelle Northwest Lab's
WS-28	C,D	Bertotti, Formisano	Instituto di Fisica "G Marconi," Rome, Italy
WS-30	F	Phillips	Pennsylvania State Univ
WS-31	E	Dessler	Rice University

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ENERGETIC PARTICLE AND TRACER EXPERIMENTS

Experiment Number	EP Subgroup Code	Experimenter(s)	Affiliation
EP-1	C	Krimigis, Bostrom	Johns Hopkins University
EP-2	D	Verzariu	Johns Hopkins University
EP-3	D	Kohl	Johns Hopkins University
EP-4	B	Armstrong	Johns Hopkins University
EP-5	A,B	Heppner	NASA/GSFC
EP-6	C	Winckler	Univ of Minnesota
EP-7	A,C	Hoch, Parks, et al	Battelle Northwest (see PD-9) Univ of Washington
EP-8	D	Hoch, Parks, et al.	Battelle Northwest (see PD-9) Univ of Washington
EP-9	A	Davis, Wescott	Geophys. Inst, Univ of Alaska
EP-10	A	Trichel	NASA/JSC
EP-11	A,B	Hess	NOAA
EP-12	A,C	Hones	Los Alamos
EP-13	B	Vasyliunas	Massachusetts Inst of Technology
EP-14	C	Thompson	Univ of Calif, San Diego
EP-15	C	Cahill	Univ of Minnesota
EP-16	C	Linson	SAI, San Diego
EP-17	C	Paulikas	Aerospace Corp
EP-18	A	Russell	Inst of Geophysics, UCLA
EP-19	B	Völk	Max-Planck Inst, Garching, Germany
EP-20	A	Chase	Univ of California at Berkeley

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WAVE-PARTICLE INTERACTIONS

Experiment Number	WP Subgroup Code	Experimenter(s)	Affiliation
WP-1	A	Kimura, Matsumoto	Kyoto University, Japan
WP-2	D	Mozer	Univ of California at Berkeley
WP-3	A,B	Oya	Kyoto University, Japan
WP-4	D	Matthews	University of Maryland
WP-5	D	Simon	Rochester University
WP-6	A	Rycroft	Univ of Southampton, England
WP-7	A,D	Taylor	NASA/GSFC
WP-8	A	Bullough, Kaiser	The University, Sheffield, England
WP-9	A	Paulikas	Aerospace Corporation
WP-10	C	McPherson, Koons	Aerospace Corporation
WP-11	C	Dowden	Univ of Otago, New Zealand
WP-12	A	Helliwell, Bell	Stanford University
WP-13	A,B	Chang, Hasegawa, Lanzerotti	Bell Laboratories
WP-15	D	Grossi	Smithsonian Astrophys Observatory
WP-16	B	Mozer, Bering	Univ of California at Berkeley
WP-17	D	Sharp	Lockheed, Palo Alto
WP-18	C	Dowden	Univ of Otago, New Zealand

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PROPULSION AND DEVICES

Experiment Number	PD Subgroup Code	Experimenter(s)	Affiliation
PD-1	A	Samir	Univ of Michigan, Tel-Aviv
PD-2	A	Smith, Grewal	Wichita State University
PD-3	A,B	Goedeke, Moe, Mukherjee, Olson	McDAC, Huntington Beach
PD-4	D	Alfvén	Univ of Calif, San Diego
PD-5	A,B	Alfvén, Fälthammar, Fahleson, Block, Bostrom, Lindberg, Danielsson, Kristoferson	Royal Inst of Technology, Sweden (Univ of Calif, San Diego)
PD-6	A	As above (PD-5)	As above (PD-5)
PD-7	A	Brace	NASA/GSFC
PD-8	A	Phillips	Pennsylvania State Univ
PD-9	B	Hoch, Stokes, Lindenmeier, Clark, Kleckner, Parks, Liemohn	Battelle Northwest Lab's Univ of Washington
PD-10	E	Calabria	Computer Sciences Corp
PD-11	D	Storey	Groupe de Recherches Ionospheriques, St. Maur, France
PD-12	E	Campbell, Matsushita	NOAA, Boulder
PD-13	A	Matthews	University of Maryland
PD-14	E	Pease	Culham Lab's, Abingdon, England
PD-15	B	Hanson, Hoffman	Univ of Texas, at Dallas
PD-16	C	Jahn, Kelly, Layton	Princeton University
PD-17	E	Hoch, Parks et al.	Battelle Northwest Lab's (see PD-9)
PD-18	C	York	Pennsylvania State Univ
PD-19	A,B	Mozer, Bering	University of Calif, Berkeley
PD-20	B	Benson	NASA/GSFC
PD-21	B	Beghin, et al	GRI, Orleans, France
PD-22	B,E	Mozer, Kelley	University of Calif, Berkeley

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PLASMA PHYSICS IN SPACE

Experiment Number	PP Subgroup Code	Experimenter(s)	Affiliation
PP-1	E	Oya	Kyoto University, Japan
PP-2	A	Falthammar, et al	Royal Inst of Technology, Sweden
PP-3	E	Freeman	Inst for Storm Research, Houston
PP-4	C	Olson	McDAC, Huntington Beach
PP-5	B	Cole	La Trobe University, Australia
PP-6	B,C	Thompson	Univ of California at San Diego
PP-7	C	Lovberg	Univ of California at San Diego
PP-8	E	Crawford, Harker	Stanford University
PP-9	B,E	Vasyliunas	MIT
PP-10	E	Grossi	Smithsonian Astrophys Obs
PP-11	E	Pedersen	ESTEC, Noordwijk, Netherlands
PP-12	A	Alfvén, Fahleson	Royal Inst of Technology, Sweden
PP-13	E	Pease	Culham Lab, Abingdon, England
PP-14	D	Aldridge	U. Alberta, Canada
PP-15	C,E	Dessler	Rice University

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WAVE CHARACTERISTICS

Experiment Number	WC Subgroup Code	Experimenter(s)	Affiliation
WC-1	A	Oya	Kyoto University, Japan
WC-2	E	Kimura, Matsumoto	Kyoto University, Japan
WC-3	E	Bertotti, Formisano	Instituto di Fisica "G Marconi," Rome, Italy
WC-4	B	Morgan, Laaspere	Dartmouth College
WC-5	H	Potemra	Johns Hopkins University
WC-6	A,H	Grossi	Smithsonian Astrophys Observatory
WC-7	D	Grossi	Smithsonian Astrophys Observatory
WC-8	A,F,G	Pedersen	ESTEC Noordwijk, Netherlands
WC-9	A,E	Hultqvist	Kiruna Geophys Observatory, Sweden
WC-10	B	McAfee	NOAA, Boulder
WC-11	B,H	Whipple, McAfee, Calvert, Goldan	NOAA, Boulder
WC-12	A,G	Inoue	University of Pittsburgh
WC-13	B,C	Barrington	Communications Res Centre, Ottawa
WC-14	A,F	Polk	Univ of Rhode Island
WC-15	A,E,F	Bearce, Baker	Naval Res Lab, Washington, D.C.
WC-16	B	Benson	NASA/GSFC
WC-17	A,F	Grossi	Smithsonian Astrophys Observatory
WC-18	A	Thomas	Imperial College, London, England
WC-19	A,E,F	Calvert	NOAA, Boulder
WC-20	C.D.E	Crawford, Harker	Stanford University
WC-21	A	Raitt	Mullard Space Science Lab's, Surrey, England
WC-22	A	Chang, Hasegawa Lanzerotti	Bell Laboratories
WC-23	C,E	Fejer	Univ of Calif at San Diego
WC-24	A	Thompson	Univ of Calif at San Diego
WC 25	A,E	Thompson	Univ of Calif at San Diego
WC-26	A,E	Hintz	Institut für Plasmaphysik, Julich, West Germany
WC-27	A	Hoch, Parks, et al.	Battelle Northwest Lab's (see PD-9)

Experiment Number	WC Subgroup Code	Experimenter(s)	Affiliation
WC-28	F	Hoch, Parks, et al.	Battelle Northwest Lab's (see PD-9
WC-29	A	Hoch, Parks, et al.	Battelle Northwest Lab's (see PD-9)
WC-30	B	Pellat	Ecole Polytechnique, Paris
WC-31	A	Thomas	Imperial College, London, England
WC-32	B	Bowhill	University of Illinois
WC-33	A	Zmuda	Johns Hopkins University
WC-34	H	Armstrong	Johns Hopkins University
WC-35	A,B,D,E	Beghin, et al.	GRI, Orleans, France

OTHER RESPONSES EXPRESSING GENERAL INTEREST, OR LESS SPECIFIC PLANS

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B. Miller	Atomic Energy Commission
D. W. Kerst	University of Wisconsin
J. P. Shkarofsky, F. Osborne	RCA, Montreal, Canada
R. L. Carovillano	Boston College
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O. Garriott	NASA/JSC

Appendix 2

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